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NASA PROJECT APOLLO WORKING PAPER NO. 1045

PROJECT APOLLO

A COMPENDIUM OF SOME SPACECRAFT SYSTEMS STUDIES RELATING TO THE MANNED LUNAR LANDING USING LUNAR ORBITAL RENDEZVOUS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

May 28, 1962

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A COMPENDIUM OF SOME SPACECRAFT SYSTEMS STUDIES RELATING TO THE MANNED LUNAR LANDING USING LUNAR ORBITAL RENDEZVOUS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 SUMMARY

The systems, spacecraft, and mission described here have been chosen to represent a current solution to the lunar landing and earth return problem by lunar orbital rendezvous. Certain problem areas have been brought to light and it is the intent of this paper to give some understanding of the total problem and to precipitate further investigations in depth. It is clear from the work presented here and from other studies made in the various technical disciplines that the lunar orbit rendezvous techniques lead to economical, time, technological and weight advantages over direct landing. The feasibility of achieving early lunar landing using the lunar orbit rendezvous technique is indicated by the systems and arrangements shown in the following pages.

2.0 INTRODUCTION

The purpose of this study is to present a broad picture of the manned lunar landing problem and a solution using a lunar orbit rendezvous technique. Lunar landing techniques using the lunar excursion module are of particular interest due to advantages in economy, time, technology, weight, performance and size. The capability of a single Saturn C-5 to launch the spacecraft for a lunar landing and the opportunity to optimize the lunar landing elements for lunar landing are considered to be major factors in favor of this approach.

The lunar orbit rendezvous technique is one involving a lunar excursion module (LEM) which is injected to a translunar trajectory along with the Apollo command and service modules. In lunar orbit the LEM with two men separates from the CM and descends to a lunar landing. The third man remains in the CM in lunar orbit. The LEM crew performs its mission goal tasks and return to lunar orbit with its records and specimens. The LEM crew performs a rendezvous and perhaps docking maneuver with the command module. The crew and payload transfer to the command module and it is injected into a transearth trajectory by the service module propulsion leaving the unmanned LEM in lunar orbit. The work presented in this paper gives a broad treatment of the spacecraft systems and mission. The LEM systems are discussed in more depth than those of other modules. Appendices are included which cover preliminary investigations in some of the technical areas.

3.0 GUIDELINES

The general guidelines are based on operation with the presently conceived Apollo Spacecraft where the lunar excursion module is a mission module.

3.1 General guidelines. - The general guidelines given here are a collection of principles to which the basic technical approach must be responsive.

3.1.1 Spacecraft scope. - The spacecraft is to be designed to land men and payloads on the lunar surface and return them to earth.

3.1.2 Lunar stay time. - The stay time on the lunar surface is to be determined by the particular mission objectives. The stay time on the lunar surface is expected to vary from 24 hours or less for the initial mission to a week or less for subsequent missions. It is anticipated that the stay time will be influenced by the lunar environment and scientific experiments to be performed.

3.1.3 Mission objectives. - Mission objectives will be centered around exploration in the vicinity of lunar touchdown. Early missions will be concerned with obtaining scientific data of the lunar surface in the immediate landing site. As information is gathered, each succeeding mission will be designed to obtain a broader range and more complete data.

3.1.4 Spacecraft flexibility. - Spacecraft flexibility is to be such that lunar landing is not unduly limited to particular regions of the surface. The spacecraft is to be designed to permit a wide selection of landing sites allowing many variations of mission objectives with a minimum change to the vehicle.

3.1.5 Mission abort. - There shall be a capability to abort the mission at any time including thrusting or lunar landing phases.

3.2 Technical guidelines. - The technical guidelines are the chosen guidelines appropriate to the mission and configuration concepts presented here. They are presented under the technical disciplines associated with the various systems. Guidelines which influence the overall spacecraft of several systems are given here. Those directly associated with the LEM systems are given in the LEM systems description.

3.2.1 Structure. - The primary structure shall utilize the bumper concept in conjunction with insulation, heat protection and meteroid protection. Materials to be employed should be such as to minimize secondary effects such as toxicity, secondary radiation, and fire hazards.

3.2.2 Guidance and control system. - Each manned module shall be capable of performing its navigation, guidance, and control tasks independent of the other modules as the primary mode.

The command module shall be capable of determining gross errors in the LEM descent and launch trajectory and recommend to the LEM appropriate maneuvers essential to execute and successful abort and rendezvous.

3.2.3 Propulsion system. - The service module systems are considered to be sized for the direct lunar launch technique. They shall be capable of meeting any additional requirements imposed by the LEM mission as outlined in Appendix A.

All spacecraft propulsion and reaction control systems shall use the same earth storable hypergolic propellants in this paper.

3.2.4 Communications system. - The spacecraft systems shall be designed to permit the LEM, CM and earth stations to communicate directly with one another except when shielded by the moon in which case advantage may be taken of any station's relay capability.

3.2.5 Environmental control system. - Each manned module shall contain its own environmental control system capable of independent operation. The extravehicular environmental control system shall be capable of transfer between modules.

3.2.6 Electrical system. - The electrical systems shall be designed to meet the power requirements during all mission phases as indicated in Appendix A.

3.2.7 Landing systems. - The lunar landing systems design shall be such that advantage can be taken of progressive increases in knowledge of the lunar environment.

3.2.8 Temperature control system. - Temperature control systems shall be designed to maintain the temperature of propellants and equipment within acceptable limits without undue constraints on spacecraft orientation.

3.2.9 Reaction control system. - Reaction control systems shall provide attitude stabilization impulse, and ullage for propulsion system ignition. The translunar injection stage shall be attitude stabilized to facilitate the LEM-command module docking maneuver.

4.0 DESIGN CRITERIA

The following criteria are the basic technical points upon which the design is based and upon which it should be judged. These criteria are limited to those which have a pronounced effect upon the mission concept, configuration, weight and general utility. The design criteria for the general spacecraft are to be taken as those presented in Reference 1. The detail criteria are considered to be those of good design practice and must be developed in the preliminary and detail design stages.

4.1 General configuration. - The LEM and command module configurations shall be compatible for free flight docking operations. The docked configuration shall be such that the occupants can transfer from one to the other without being exposed to the environment of space. An external hatch in the LEM shall be provided to allow exit into space while in the docked position. Systems shall be arranged and access shall be provided for efficient maintenance, repair and checkout.

4.1.1 Stowage. - The LEM shall be capable of being stowed in an adapter between the Apollo Service Module and the launch vehicle. The adapter shall present a clean aerodynamic shape, and may or may not be an integral part of the LEM structure. If the adapter is not used as an integral part of the LEM structure then the LEM must be capable of being extracted from a 154" O.D. adapter. The adapter is to be included in the total escape weight of the spacecraft.

4.1.2 Visibility. - The configuration shall provide ample direct visibility for the crew to take advantage of their natural capabilities in mission phases including landing, rendezvous, docking and attitude control.

4.2 Structure. - The LEM is to be supported from earth launch up to translunar injection in a specially designed adapter. The adapter shall provide adequate structural integrity for flight and ground handling. The attachment of the LEM to the adapter shall permit reliable assembly and separation. Access panels shall be provided to permit ground and flight servicing and maintenance.

4.2.1 Design factors. - Design factors as given in reference 1 shall apply to the total spacecraft except that tankage in the LEM shall be designed using the maximum design factors for sizing analysis.

4.2.2 Design cases. - The structural design shall take into account all loads and environments encountered during the mission. The following design considerations are of particular interest in the LEM design but should not be construed to be all-inclusive.

Design cases are to be rationally determined incorporating externally applied loads and environments as well as the response of the structure and systems.

4.2.2.1 Accelerations. - Loads due to basic accelerations as imparted by the propulsion and landing systems are to be superimposed on the dynamic loads which occur in response to environments, structural and mass characteristics, and systems characteristics.

4.2.2.2 Moments. - Moments and associated response as imparted by maximum gimbal or thrust misalignment are to be considered in developing design cases.

4.2.2.3 Ground handling. - Ground handling design loads shall recognize the operational problems associated with normal ground handling, erection and testing. Systems will be designed to minimize the compromises made necessary by ground handling cases.

4.2.2.4 Noise and vibration. - Noise and vibrations encountered during all mission phases are to be withstood and attenuated by the structure.

4.2.3 Baffling. - Tankage baffling will be provided.

4.2.4 Meteoroid protection. - Meteoroid protection for the entire LEM during translunar flight shall provide a reliability of .990 of no penetration based on Whipple's distribution of 1961 and the Summer's penetration equation utilizing a 1.5 correction factor for finite plates. A reliability of .999 is required for the LEM for the period between its departure and return to the command module.

4.2.5 Bumper penetration. - For meteoroid protection sizing, a bumper type structure shall be designed to reduce the penetration 80 percent and filled constructions to reduce penetration 84 percent.

4.3 Guidance and control. - The guidance and control system shall be capable of performing in an onboard control automatic mode and manual control which is to be considered primary.

4.3.1 Lunar landing terminal condition. - The Guidance and Control System shall provide a capability of accomplishing lunar touchdown within the following velocity limits:

Horizontal Velocity 0-5 ft/sec.
Vertical Velocity 0-10 ft/sec.

4.3.2 Rendezvous. - The Guidance and Control System shall provide rendezvous capability in lunar orbit.

4.3.3 Hover and translation. - The Guidance and Control System in conjunction with the propulsion system and the reaction control system shall provide hover capability at an altitude of 350 feet for 60 seconds using automatic or manual modes of control. Horizontal translation capability up to 1000' after the hover for an additional 60 seconds shall be provided.

4.3.4 Altitude. - In conjunction with the Communications System, the Guidance and Control System shall determine altitude within $\pm$ 50 feet from 1000 ft. to 100 miles. At altitudes under 1000 ft., the accuracy should be $\pm$ 5 ft. for lunar touchdown.

4.3.5 Attitude. - In conjunction with the Reaction Control System, the Guidance and Control System shall maintain the proper attitude during all phases of the mission.

4.4 Propulsion system. - The propulsion systems shall be designed to cater for the maximum payloads and to be staged as indicated in weight and balance Section 10, Table 29. Velocity increments to be used in sizing the systems are to be the characteristic velocities with 5 percent reserve as given in Section 5, Table 1.

4.5 Communications system. - The communication system design criteria are inherent in the systems description in Section 9.4.

4.6 Environmental control system. - The environmental control system shall contain a split supply system. One supply system shall be in operation from the orbit phase to the lunar touchdown phase and shall cater for 24 hours of lunar exploration and shall be jettisoned prior to lunar launch. The second system shall be capable of supplying needs for 24 additional hours.

4.6.1 Capability. - The systems shall be capable of meeting the crew requirements given in Section 7. The environmental control unit for the extravehicular suits shall be capable of operation independent of and in conjunction with the LEM ECS.

4.7 Electrical power and distribution. - The electrical power and distribution system shall be split so that lunar touchdown and lunar stay time requirements will be located with equipment left on the moon while power equipment required to rendezvous with the command module will be located in the lunar launch portion of the LEM.

4.8 Landing system. - The landing system is to be designed to cater for a variety of rational combinations of environments and terminal conditions. The landing system is to be capable of providing stability under conditions of landing on 4 or less pads and at a range of vertical and horizontal velocities. Landing attitude shall be maintained to prevent toppling or tumbling.

4.8.1 Landing surface environment. - The landing surface conditions are assumed to be those predicted in reference 2. The most adverse combinations of dust layer, protuberance, rock froth and depressions are to be considered at each landing pad. The most adverse surface slope and landing direction is to be considered.

4.8.2 Landing weight. - The maximum landing weight is to be that associated with a minimum velocity requirement and maximum payload delivered to the lunar surface. This value is to be at least 16,000 pounds.

4.8.3 Thrust termination. - Thrust shall be terminated prior to touchdown such that detrimental effects in the landing stability are eliminated.

4.8.4 Touchdown velocities. - The landing system shall be designed to cater for any combinations of horizontal and vertical velocities within the following limits.

4.8.4.1 Structural considerations. - Vertical velocities shall be 0 to 10. feet per second. Horizontal velocities shall be 0 to 5. feet per second.

4.8.4.2 Stability considerations. - Vertical velocities shall be 0 to 10. feet per second. Horizontal velocities shall be 0 to 7. feet per second.

4.8.5 Angular momentum. - Angular momentum prior to impact is considered to be zero.

4.8.6 Impact acceleration. - The maximum acceleration to be imparted to the spacecraft or its equipment during the landing impact is to be limited to 120 feet/second/second.

4.9 Temperature control. - Passive temperature control through utilization of inherent structure, insulation and surface treatment shall be provided throughout all phases of the mission. Temperature control shall be provided for crew comfort, operational systems, and functional systems in accordance with mission requirements. Active systems shall be considered only where the passive systems are clearly inadequate.

4.10 Reaction control system. - The LEM reaction control system shall provide control of the six degrees of freedom for attitude and vernier thrust control during coast, thrusting of main propulsion systems, and docking maneuvers.

4.10.1 Terminal docking condition. - The reaction control system, in conjunction with visual guidance shall control the LEM within the following conditions:

a. Impact velocity along the X axis shall be less than 1.0 ft. per sec.

b. Lateral velocity in the Y-Z plane at impact shall be less than 1.0 feet/second.

c. Angular velocities in roll shall be less than 1.0 degrees/sec. Angular velocity in pitch or yaw shall be less than 2.0 degrees/second.

d. Angular misalignments at impact shall be less than 2 degrees.

e. Linear misalignments at impact shall be less than 0.25 inches.

4.10.2 Thrust eccentricity. - The LEM reaction control system shall supply moments to counteract a misalignment of the maximum thrust vector from the center of gravity of 0.8 inches.

4.10.3 Ullage. - The LEM reaction control system shall supply thrust required to settle propellants for ignition of the main propulsion system. This is to be considered as 7 starts, .01g minimum, for 0.1 seconds.

4.10.4 Propellant sizing. - The reaction control system propellant shall be sized to correct for a continuous misalignment of the thrust vector from the center of gravity of 0.4 inches. Each system shall be sized for this offset and ullage requirements with a 25 percent reserve.

4.10.5 Positive expulsion. - The reaction control system shall have positive expulsion tanks.

4.10.6 Pulse modulation. - The reaction control system shall be pulse modulated for control.

4.10.7 Redundant systems. - The reaction control system shall have two interconnectable redundant systems each capable of satisfying mission requirements.

4.10.8 Interconnect with propulsion system. - There shall be a capability to interconnect the reaction control system to the main propulsion system during thrusting.

TABLE 1. - DESIGN VELOCITY INCREMENTS

	Characteristic Velocity ft/sec	Characteristic Velocity + 5 percent ft/sec
Translunar midcourse correction	200	
Retro into 600,000 ft. circular lunar orbit	3415	
Lunar orbit plane change	93	
SM total increment into lunar orbit	3708	3893
Transfer circular orbit to equal-period orbit	465	
Brake to zero velocity near lunar surface	6040	
Hover, translation and touchdown	738	
LEM landing stage	7243	7605
Ascend into elliptic orbit having a 600,000 ft. apocynthion and 50,000 ft. pericynthion(T/W =.4)	5975	
Higher-energy trajectory (Additional increment required)	45	
Cross-plane maneuver for takeoff (10)	20	
Circularize in 600,000 ft. orbit	305	
Rendezvous and docking in lunar orbit	50	
LEM launch stage	6395	6715
Escape from lunar orbit	4097	
Transearth midcourse correction	200	
SM return to earth's atmosphere	4297	4512

5.0 PERFORMANCE CRITERIA

Performance criteria for the general spacecraft shall be those given in reference 1 with the following special considerations for the LEM mission.

5.1 Growth contingency. - A set of criteria are presented here which will permit growth in weight, maneuver velocity reserve, time, payload and geometry. The approach taken here does not compromise the spacecraft's versatility in other missions.

5.1.1 Saturn C-5 launch vehicle. - The propulsion systems and other systems are sized such that they will not be critical when and if the earth escape weight approaches the minimum guaranteed payload, all engines burning and optimized for the Saturn C-5. This weight is considered to be 80,000 pounds. The surplus payload capability is considered to be landed on the lunar surface and not returned to lunar orbit.

5.1.2 Non-propulsive payloads. - All payloads, excluding service module propulsion system and LEM propulsion system, are considered to have a growth potential of 25 percent over the present best estimate of the flight item weights.

5.1.3 Velocity reserve. - Propulsion systems are sized based on a 5 percent surplus over the best estimate of the characteristic velocity increments, including gravity losses, for each phase of the mission. Velocity increments for plane changes, midcourse correction, rendezvous and docking are considered to be conservatively estimated and the 5 percent surplus is applied here as well. These design velocities are given in table 1.

5.1.4 Thrust to weight ratio. - The thrust to weight ratio of the LEM is sized for the lunar landing trajectory having a ratio of .37 initially in lunar orbit for mission history shown in table 28, column 3. The engine is throttleable and the gravity losses on lunar launch are based on the same low initial ratio although a ratio of 1.2 is available. This higher T/W ratio permits some variation in normal launch or abort trajectories. The T/W ratio varies with the missions shown in table 28. The final optimization of this parameter is to be the subject of further study.

5.1.5 Geometry. - The cabin is sized to permit the crew to perform the tasks they have to perform and gives considerable freedom in inboard payload geometry. A much greater freedom exists for payloads stowed outboard and returned to lunar orbit. A greater freedom again exists for equipment landed on the lunar surface being carried there on the landing tankage stage.

6.0 NATURAL ENVIRONMENT

The design and operational procedures are in accordance with natural environment data presented in reference 2 with the following superceding considerations.

6.1 <u>Radiation flux</u>. - The radiation environment for the LEM mission considers both primary and secondary particles produced by proton interactions.

6.1.1 <u>Primary solar proton energy-flux relationships</u>. - The flux-energy relationships are described by the following equations derived from reference 51.

$5 \text{ MEV} < E \leq 60 \text{ MEV} \quad N = 2.5 \times 10^{11} E^{-2.07}$ N = Number of particles greater than the energy E

$60 \text{ MEV} < E \leq 00 \quad N = 5.48 \times 10^{14} E^{-3.95}$ E = Energy of particle

The total number of particles in the energy range between 5 MEV and 100 MEV is 2.34×10^{8} protons/CM^2 steradian.

6.1.2 <u>Secondary particles</u>. - The upper limit of secondary particle production is determined by assuming a maximum proton cross-section of 1 barn. The secondary flux is calculated from the following equation:

$$N_s = \frac{(\sigma \times 10^{-24})(6.02 \times 10^{23}) \left[N\ (E > E_o)\right] X}{A}$$

N_s = # of recording particles

σ = Cross-section

A = Atomic No.

N = Number of particles (primary)

6.2 <u>Meteroid flux</u>. - The meteroid flux for the LEM mission is based on a modification of Whipple's 1957 distribution for sporadic meteroids. The distribution is given in table 2. The probability of encounter for a particular magnitude meteroid is given by the following equation:

$$1 - P_e = F_t\, TA$$

$1 - P_e$ = Probability of encounter

F_t = Flux for a particular magnitude meteroid

T = Time duration of mission hr.

A = Area, sq. ft.

6.3 Lunar surface environment. - The characteristics of the lunar surface are given in reference 2.

[redacted]

TABLE 2. - WHIPPLE'S DISTRIBUTION FOR SPORADIC METEOROIDS (1961)

Visual magnit.	Mass slugs	Mass grams	Diameter* microns	Diameter* inches	Daily accretion of earth	Velocity KM/sec.	Velocity ft/sec.
0	$1.71x10^{-4}$	2.5	11,070	.435	$3.3x10^{5}$	28	91,900
1	$6.82x10^{-5}$	$9.95x10^{-1}$	8,160	.320	$1.225x10^{6}$	28	91,900
2	$2.71x10^{-5}$	$3.96x10^{-1}$	6,000	.236	$4.55x10^{6}$	28	91,900
3	$1.08x10^{-5}$	$1.58x10^{-1}$	4,410	.173	$1.69x10^{7}$	28	91,900
4	$4.30x10^{-6}$	$6.28x10^{-2}$	3,250	.127	$6.27x10^{7}$	28	91,900
5	$1.71x10^{-6}$	$2.50x10^{-2}$	2,390	$9.36x10^{-2}$	$2.33x10^{8}$	28	91,900
6	$6.82x10^{-7}$	$9.95x10^{-3}$	1,760	$6.91x10^{-2}$	$5.84x10^{8}$	28	91,900
7	$2.71x10^{-7}$	$3.96x10^{-3}$	1,290	$5.07x10^{-2}$	$1.47x10^{9}$	28	91,900
8	$1.08x10^{-7}$	$1.58x10^{-3}$	951	$3.74x10^{-2}$	$3.69x10^{9}$	27	88,600
9	$4.30x10^{-8}$	$6.28x10^{-4}$	700	$3.75x10^{-2}$	$9.26x10^{9}$	26	85,300
10	$1.71x10^{-8}$	$2.50x10^{-4}$	514	$2.02x10^{-2}$	$2.33x10^{10}$	25	82,000
11	$6.82x10^{-9}$	$9.95x10^{-5}$	379	$1.49x10^{-2}$	$5.84x10^{10}$	24	78,700
12	$2.71x10^{-9}$	$3.96x10^{-5}$	279	$1.09x10^{-2}$	$1.47x10^{11}$	23	75,500
13	$1.08x10^{-9}$	$1.58x10^{-5}$	205	$8.04x10^{-3}$	$3.69x10^{11}$	22	72,200
14	$4.30x10^{-10}$	$6.28x10^{-6}$	151	$5.93x10^{-3}$	$9.26x10^{11}$	21	68,900
15	$1.71x10^{-10}$	$2.50x10^{-6}$	111	$4.35x10^{-3}$	$2.33x10^{12}$	20	65,600
16	$6.82x10^{-11}$	$9.95x10^{-7}$	81.6	$3.20x10^{-3}$	$5.84x10^{12}$	19	62,300
17	$2.71x10^{-11}$	$3.96x10^{-7}$	60	$2.36x10^{-3}$	$1.47x10^{13}$	18	59,100
18	$1.08x10^{-11}$	$1.58x10^{-7}$	44.1	$1.73x10^{-3}$	$3.69x10^{13}$	17	55,800
19	$4.30x10^{-12}$	$6.28x10^{-8}$	32.5	$1.27x10^{-3}$	$9.26x10^{13}$	16	52,500
20	$1.71x10^{-12}$	$2.50x10^{-8}$	23.9	$9.36x10^{-4}$	$2.33x10^{14}$	15	49,200
21	$6.82x10^{-13}$	$9.95x10^{-9}$	17.6	$6.91x10^{-4}$	$5.84x10^{14}$	15	49,200
22	$2.71x10^{-13}$	$3.96x10^{-9}$	12.9	$5.07x10^{-4}$	$1.47x10^{15}$	15	49,200
23	$1.08x10^{-13}$	$1.58x10^{-9}$	9.5	$3.74x10^{-4}$	$3.69x10^{15}$	15	49,200
24	$4.30x10^{-14}$	$6.28x10^{-10}$	7.00	$2.75x10^{-4}$	$9.26x10^{15}$	15	49,200
25	$1.71x10^{-14}$	$2.50x10^{-10}$	5.14	$2.02x10^{-4}$	$2.33x10^{16}$	15	49,200

* Diameters based on ρ_m = 3.5 grams/cc.

[redacted]

7.0 CREW REQUIREMENTS

Design and operational procedures for the general spacecraft shall be in accordance with the crew requirements data presented in reference 1. Data given below are to be considered for operation with the LEM.

7.1 Metabolic requirements. - The average daily metabolic requirements for each crew member are listed below.

Oxygen Consumption	2.0 lb/day/man
Carbon Dioxide Output	2.4 lb/day/man
Heat Output	12,000 BTU/day/man
Water Consumption	13.36 lb/day/man

7.2 Cabin pressure and suit pressure. - The cabin pressure nominal limits shall be 5.0 psia with a suit pressure of 3.5 psia. The suit pressure emergency limit shall be 3.5 psia when the cabin is vented to the lunar environment.

7.3 Suit relative humidity. - The suit relative humidity non-stressed limits shall be 40 percent minimum and 65 percent maximum. The emergency and stressed limits are presented in figures 3 and 4 of reference 1.

7.4 Crew and equipment. - The LEM crew and equipment, other than the seats, leave the Apollo Command Module through the air lock ready to perform their tasks for the Apollo LEM mission.

7.4.1 Crew. - The LEM crew is to consist of two men from the Apollo spacecraft.

7.4.2 Equipment. - Equipment described here is for general crew support in the LEM. Other equipment for LEM operations purposes and for nonoperational crew tasks are discussed in the Systems Description Section 9.

7.4.2.1 Space suit. - Each crew member is to be equipped with a space suit, helmet and boots suitable for lunar operation, and satisfying ingress and egress requirements for the command module and the LEM. The space suit must be compatible with the Environmental Control System, Communication System and crew activity requirements.

8.0 SPACECRAFT CONFIGURATION

The complete general spacecraft configuration is to be that as described in reference 1 with the LEM being considered as a mission module similar to the Space Laboratory. The following describe the specific configuration for the LEM mission. The configuration variations during the mission are given in Appendix A.

8.1 Launch configuration. - The Spacecraft Launch Configuration is shown in figure 1. The S IV B stage is considered to be 260 inches in diameter.

8.2 Space flight configuration. - The spacecraft configuration after tower separation, at injection on the translunar trajectory, the initial docking configuration and the translunar configuration are shown in figure 2.

8.2.1 Stowed configuration. - The LEM is stowed in the adapter region attached at the four landing gear fittings to the lower end of structural rails on the inside of the adapter. The landing gear is stowed extended aft by having each of the four central struts slide down in its housing on the landing stage.

8.2.1.1 Access. - There is free access to the LEM upper cabin region through the blowout panels in the adapter opposite the LEM access hatch. These panels serve the service module systems as well. There is free access to the LEM lower propulsion, equipment and gear region through the blowout panels in the interstage structure. These panels serve the forward mounted equipment on the S IV B stage as well.

8.2.1.2 Service module-adapter interface. - The service module is attached to the adapter by remotely initiated quick acting detachments.

8.2.2 Initial docking configuration. - The CM-SM combine separates from the adapter. The SM reaction control system is used to maneuver the combine to perform the docking operation. The CM crew observes the docking interface through the CM air lock hatches' windows. The docking attachments are fixed and the quick disconnects holding the LEM at the bottom of the adapter guide rail are activated. The attitude stabilization system on the S IV B stage maintains the S IV B and housed LEM in an acceptable orientation during the docking maneuver.

8.2.3 Translunar configuration. - The CM-SM combine extracts the LEM from the adapter guided along the guide rails. The landing gear is deployed remotely and inspected at leisure. The spacecraft remains in this configuration until separation of the LEM in lunar orbit for lunar landing.

8.3 Lunar excursion module configuration. - The initial developments of the Lunar Excursion Module (LEM) general landing configuration are shown in figure 3. The following configurations demonstrate the staging interface, launch configuration, inboard profile, and geometry.

8.3.1 Launch configuration. - The Launch Configuration is shown in figure 4. The landing tankage, gear and payload stage is shown below the launch stage. The quick disconnects for structural, systems and propellant umbilicals have been activated and have permitted the launch configuration to separate in free flight, during touchdown or after landing.

8.3.2 Inboard profile. - The initial developments of the inboard profile are shown in figure 5. The plumbing, interconnect systems and interfaces are not shown. The landing stage propellants feed the launch stage tankage through the proper umbilical and vent systems. The landing stage oxygen stores and power supply feed the applicable equipment directly or through umbilicals leaving the launch stage systems at maximum capacity. Scientific payloads are stowed in the landing stage until samples and equipment are deposited in the launch stage.

8.3.3 Geometry. - The LEM external geometry is given in figure 6.

8.4 Command and service modules. - The command and service modules are considered to be identical to those given in reference 1 with non-propulsive target weights as given in reference 3. The interface between the CM and the LEM at docking indicates a need for special seal, attachment and airlock considerations. An air lock scheme is discussed in Appendix E. The CM crew utilizes the windows in the air lock hatches to enhance the control through direct visibility during docking maneuvers.

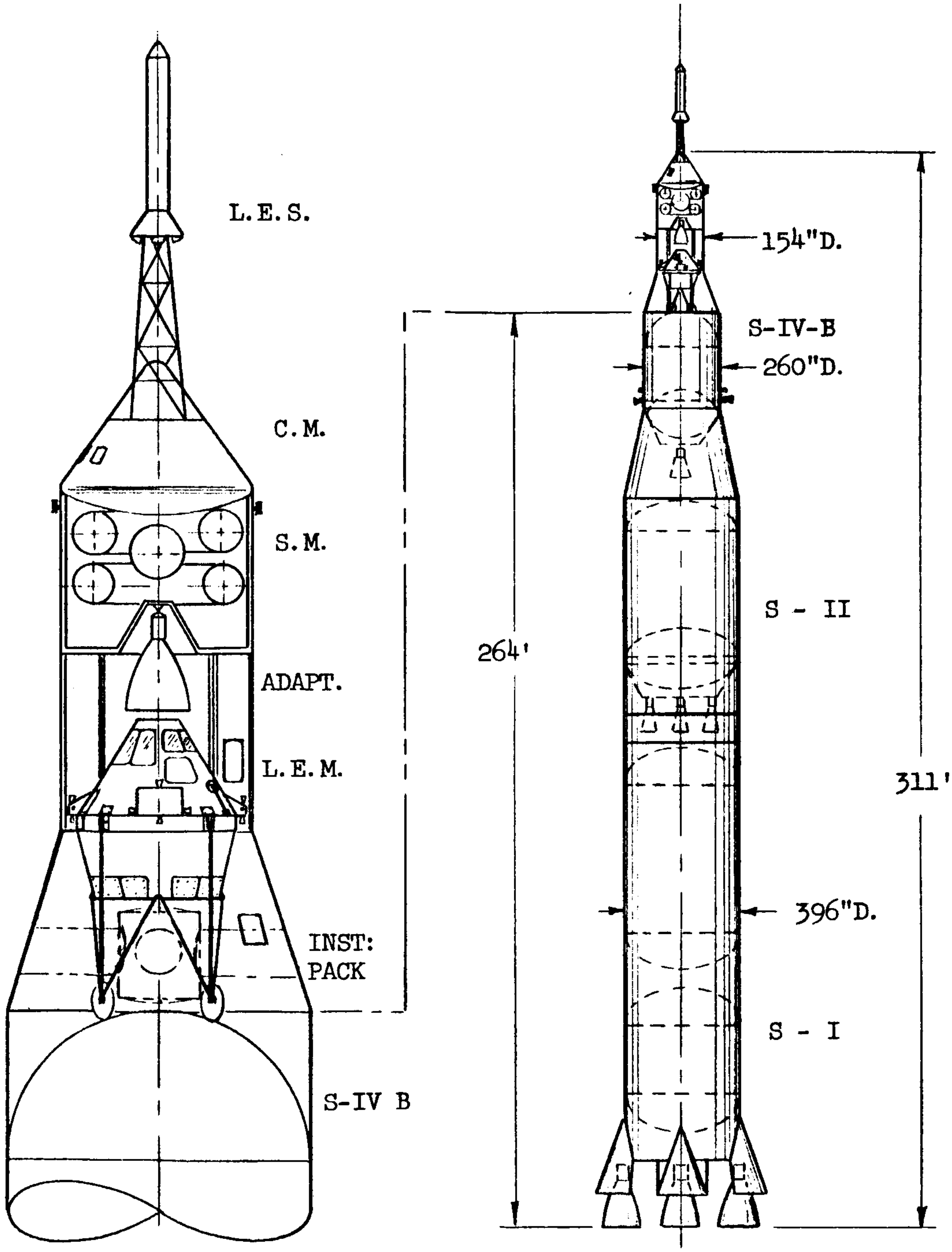
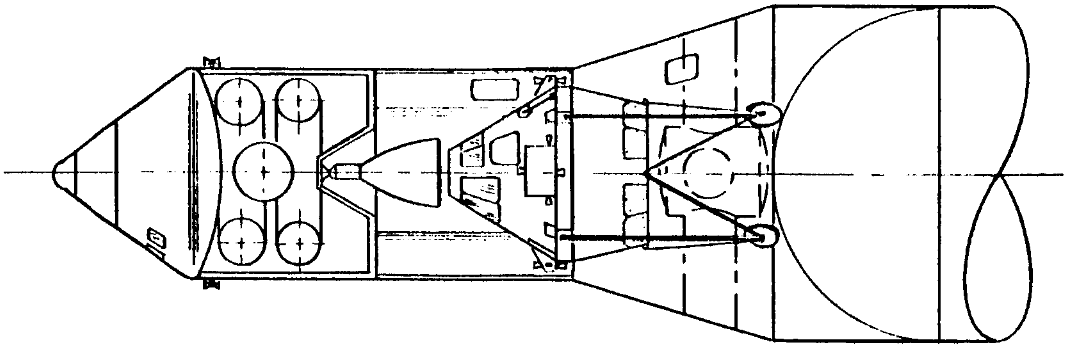
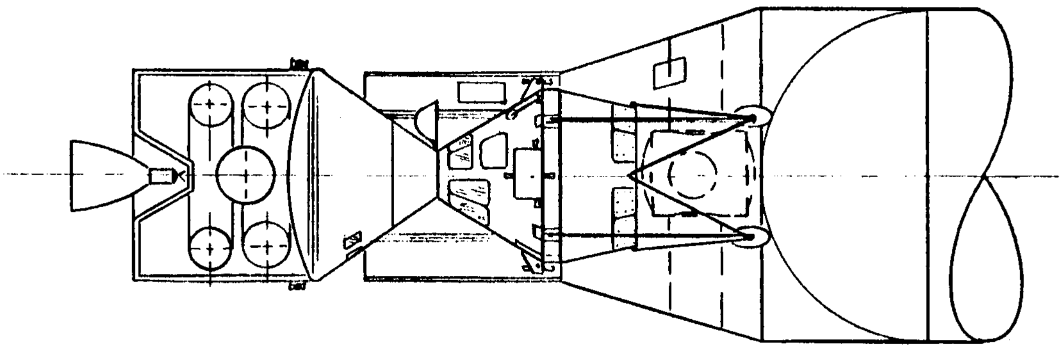


FIGURE 1.- SPACECRAFT LAUNCH CONFIGURATION

STOWED CONFIGURATION



INITIAL DOCKING CONFIGURATION



TRANSLUNAR CONFIGURATION

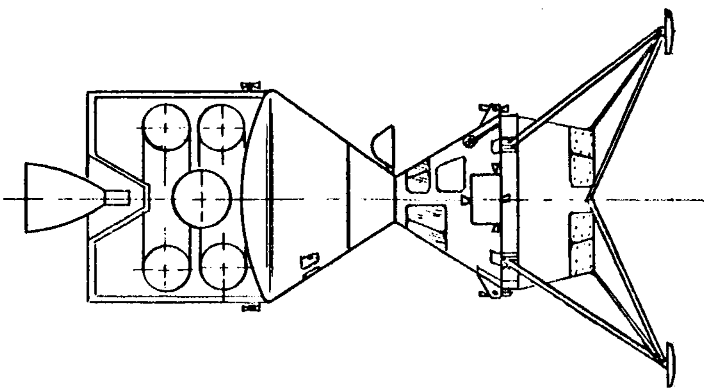


FIGURE 2.- SPACE FLIGHT CONFIGURATIONS

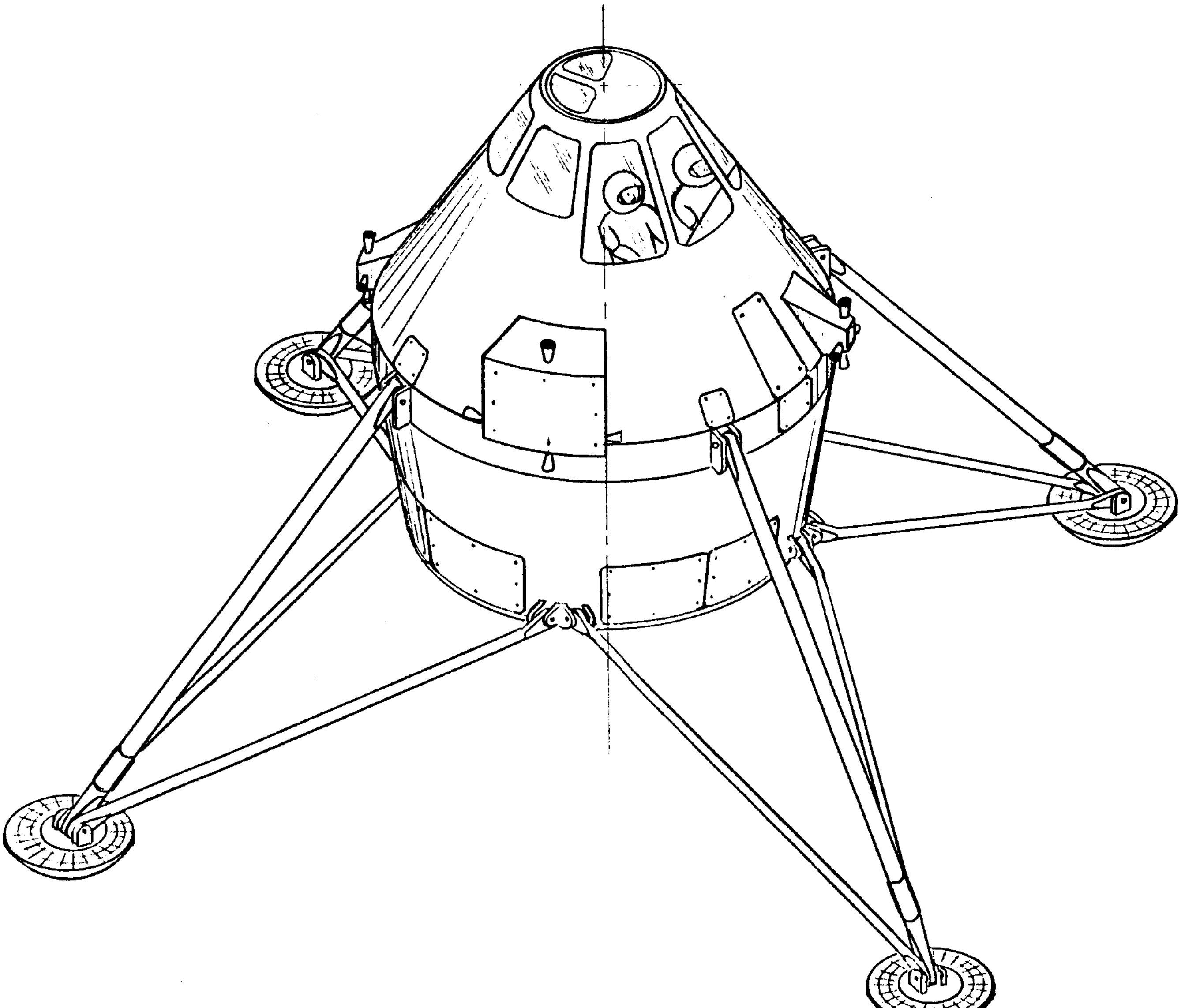


FIGURE 3(a)- VERSION 1

LUNAR EXCURSION MODULE

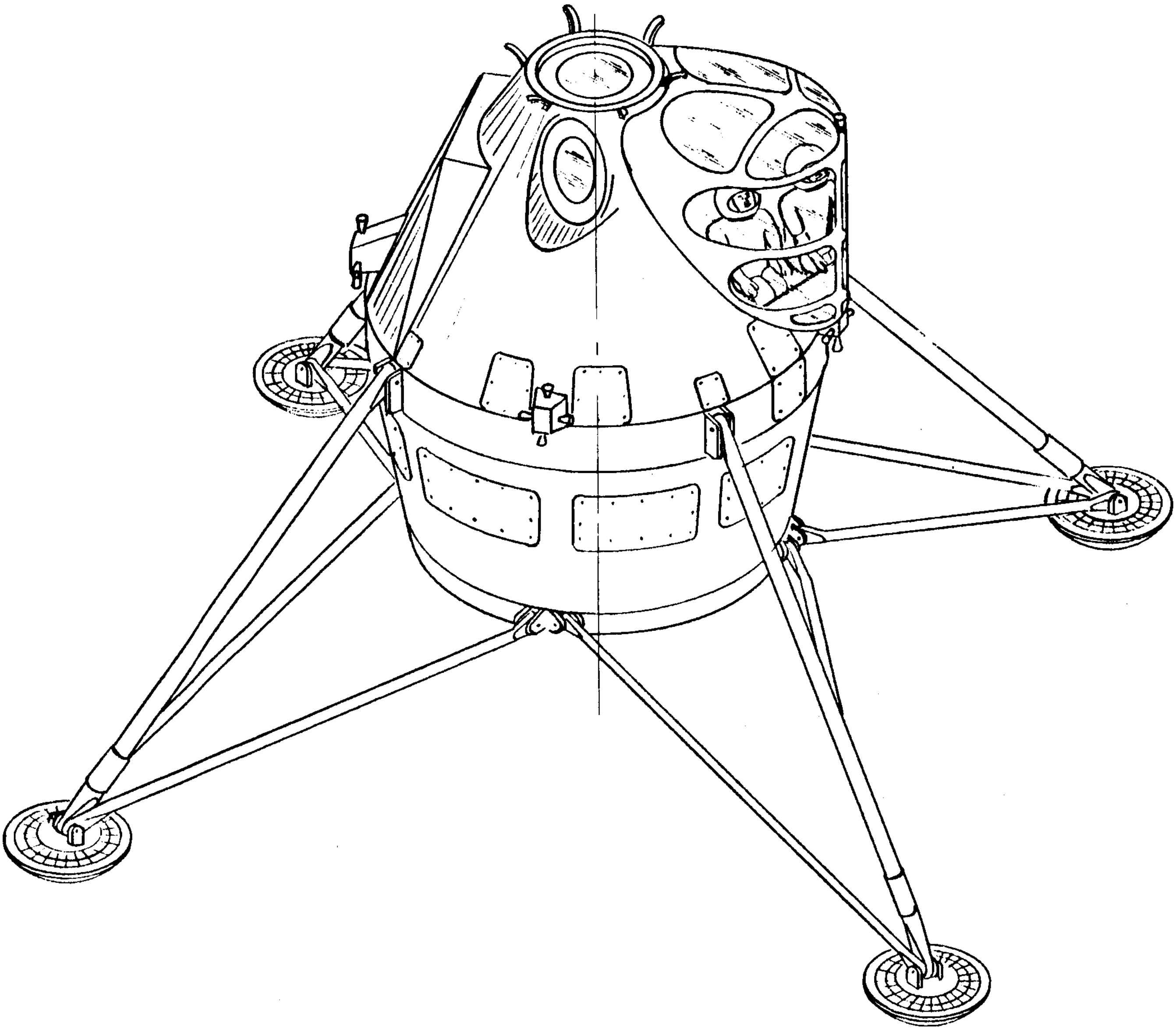


FIGURE 3(b)-VERSION 2 (Concluded)

FURTHER DEVELOPMENTS LUNAR EXCURSION MODULE

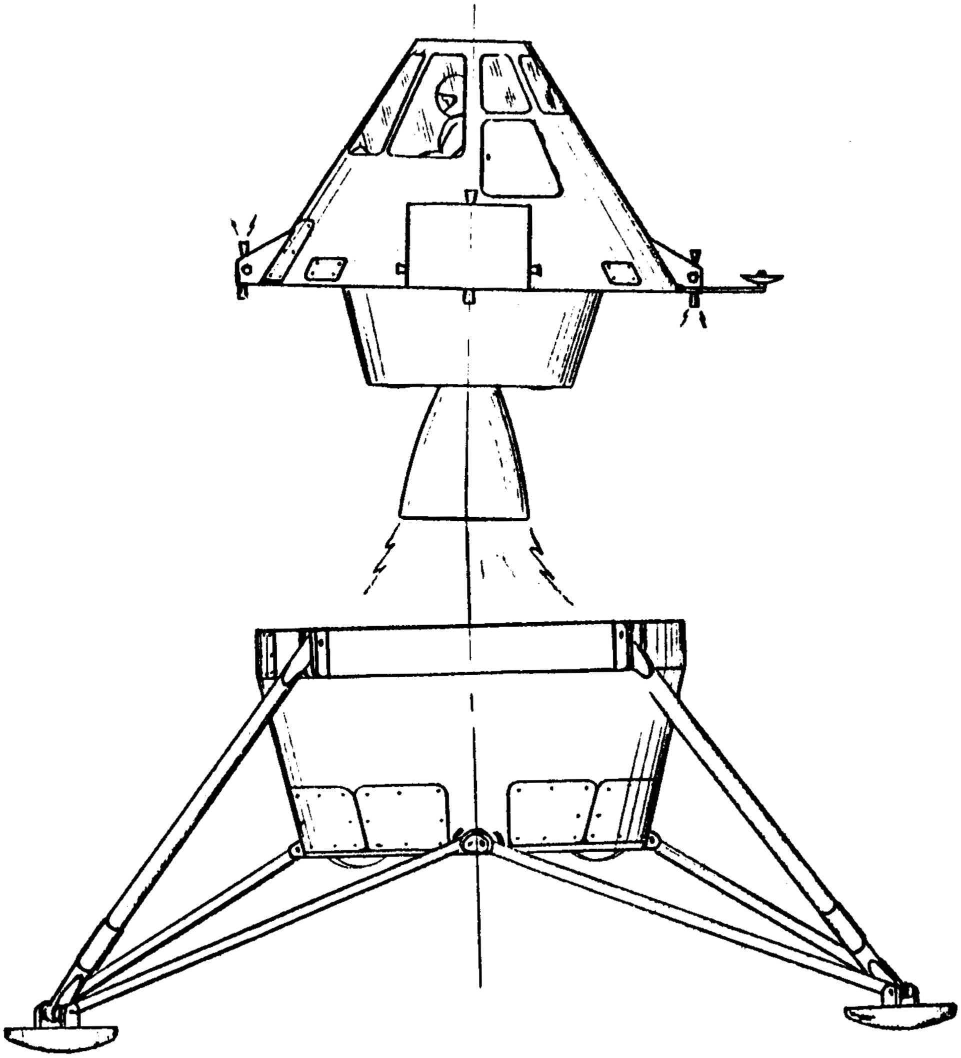


FIGURE 4.- LUNAR EXCURSION MODULE

LAUNCH CONFIGURATION

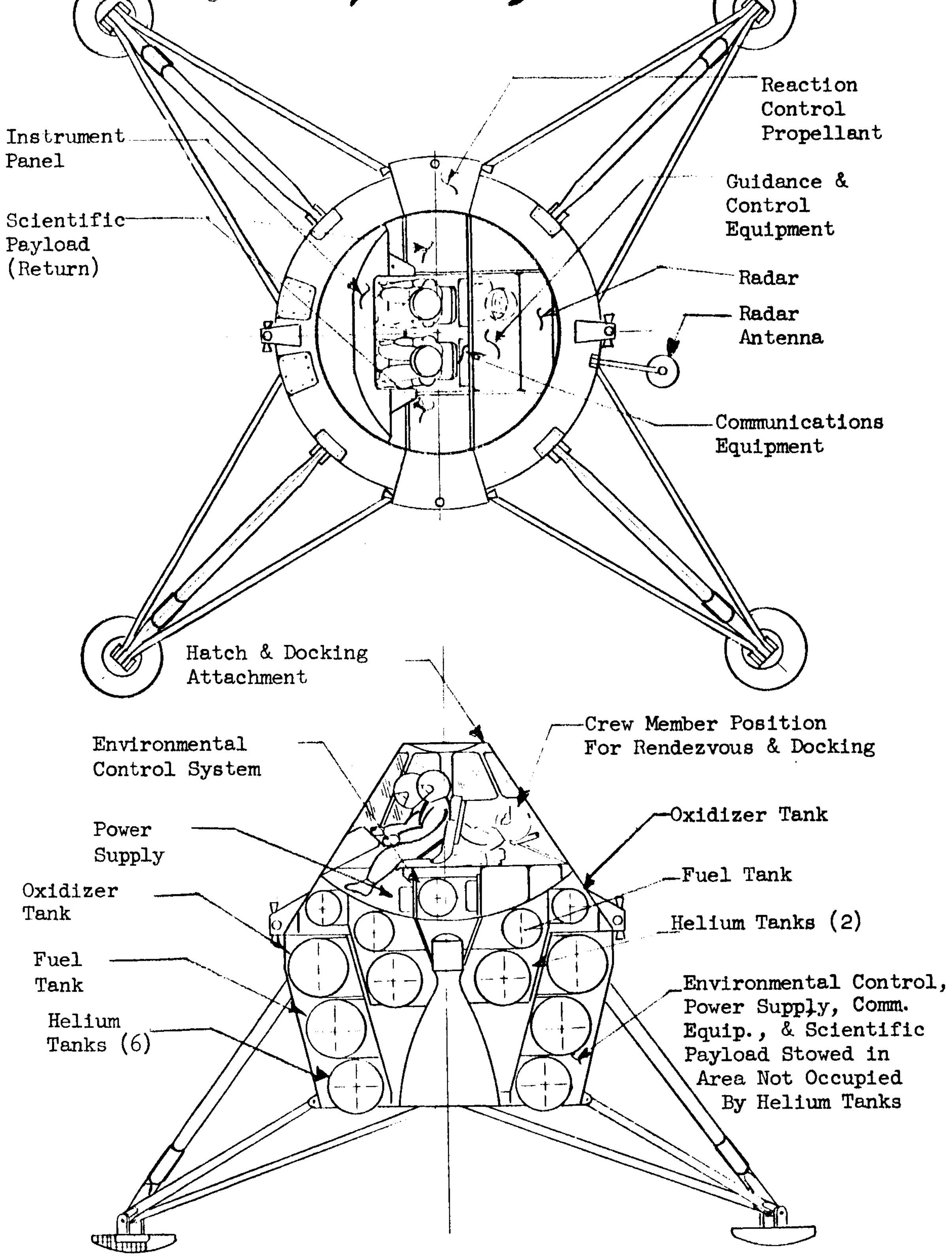


FIGURE 5(a).- LUNAR EXCURSION MODULE

INBOARD PROFILE

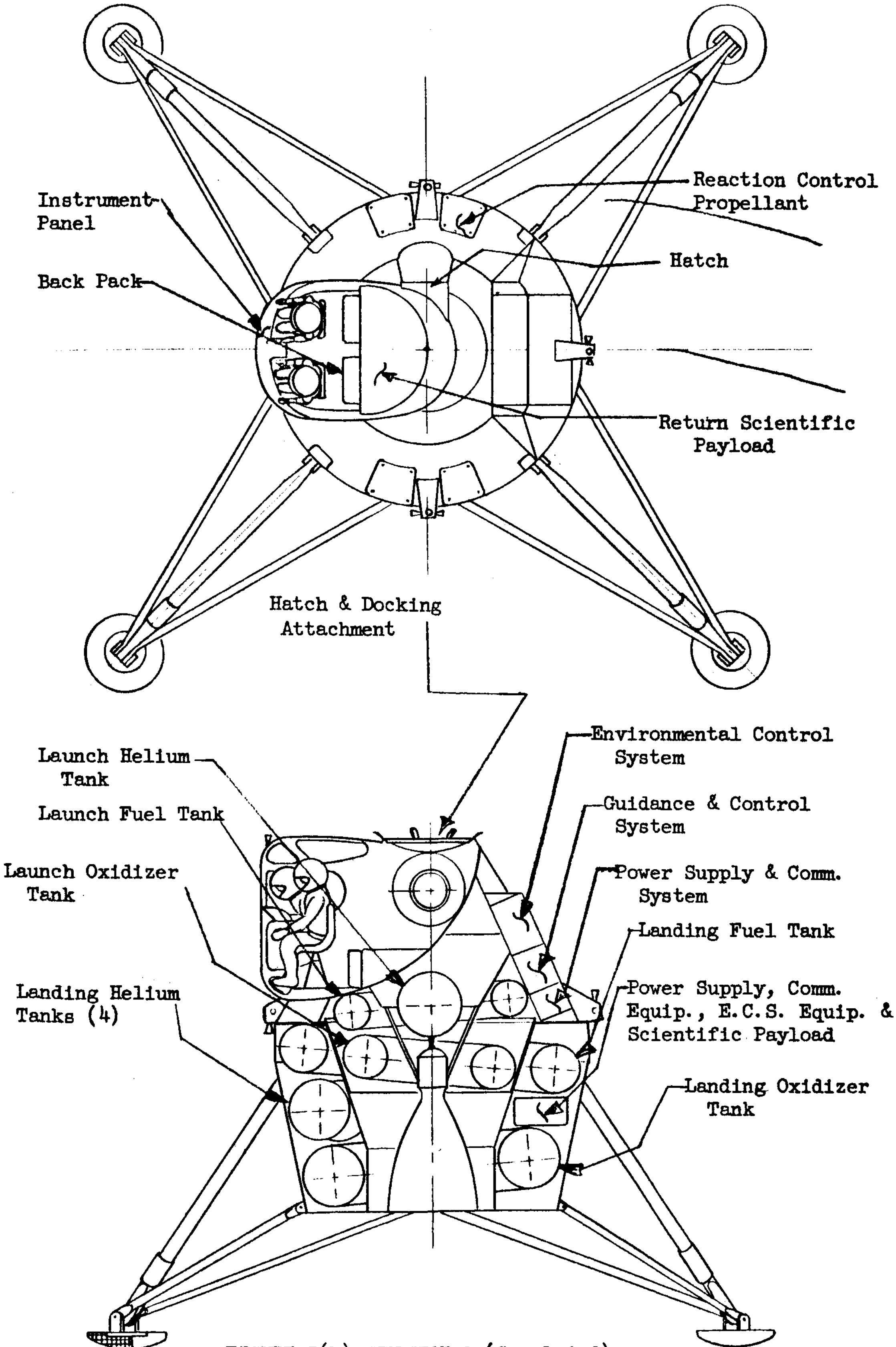


FIGURE 5(b)- VERSION 2 (Concluded)

FURTHER DEVELOPMENTS LUNAR EXCURSION MODULE

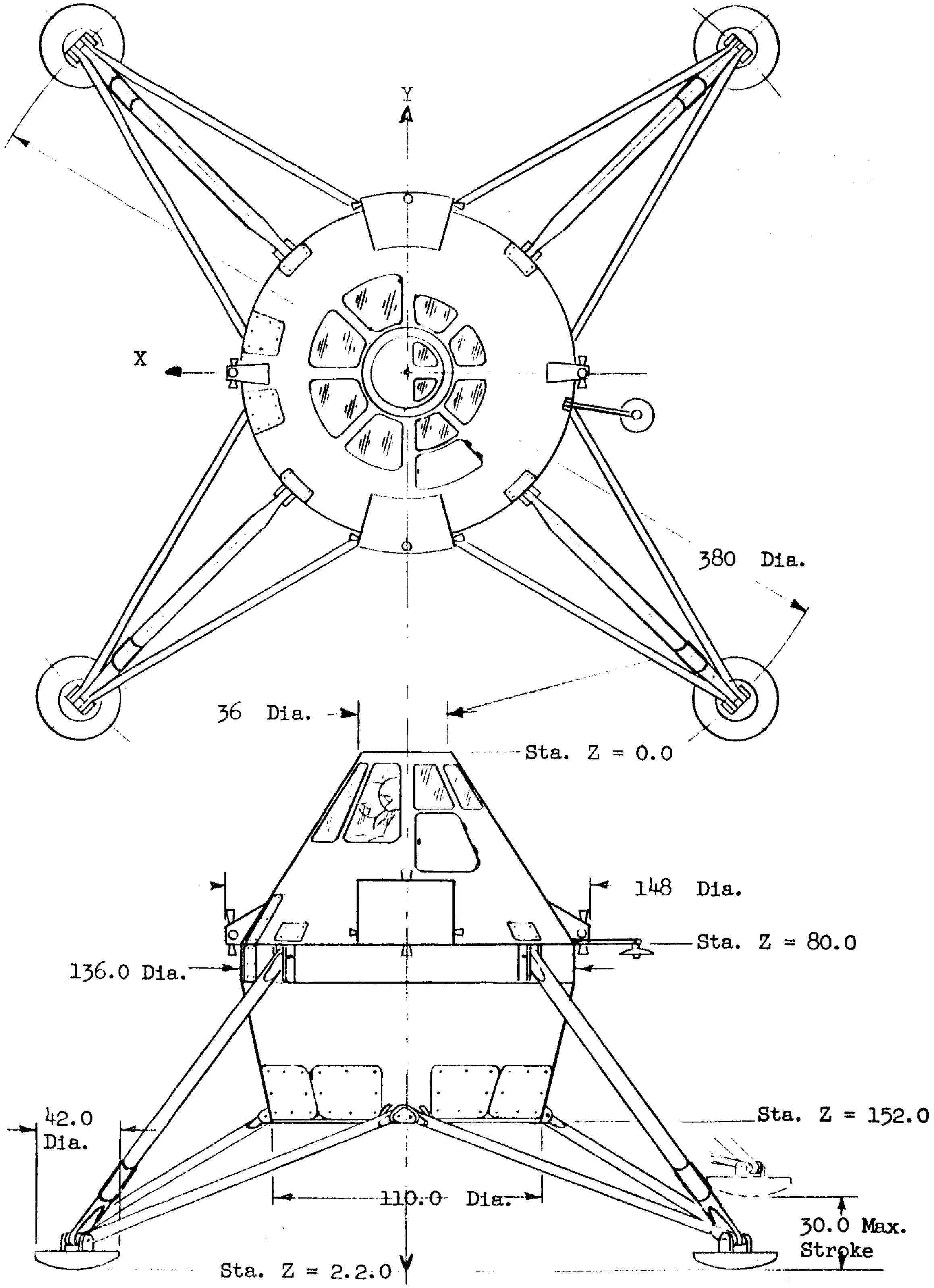


FIGURE 6.- LUNAR EXCURSION MODULE
EXTERNAL GEOMETRY

9.0 SYSTEMS DESCRIPTION

A brief description of the systems comprising the LEM is presented in this section.

9.1 Crew and equipment.- The flight crew, their responsibilities and personal support equipment are described here.

9.1.1 Flight crew. - The commander (pilot) and the pilot-system manager from the command module comprise the LEM flight crew and the second-in-command pilot-navigator remains with the command module. Each crew member performs the functions assigned in Reference 1 with the additional requirements that they participate in the lunar surface operations and preparation of records according to Appendix B.

9.1.2 Crew Support. - Each crew man shall be provided with a seat capable of supporting against acceleration loads. The seat shall be adjustable to provide for a comfortable rest position and for rendezvous and docking visibility.

9.1.3 Restraint system. - A restraint system shall be provided with each seat. It shall provide adequate restraint for all nominal and emergency flight phases. Lunar landing loads and liftoff accelerations are particularly significant in design of this system.

9.1.4 Space suit. - The space suit for lunar exploration is to be developed under separate specifications. Weight estimates are based on suits presently under development.

9.1.5 Food. - The food items shall constitute of low bulk diet. The food shall be of the dehydrated, frozen, dried or similar type that is reconstituted with water or does not require reconstitution. There is no requirement for refrigeration. Advantage shall be taken of the lunar gravity influence on food and drink.

9.1.6 Water. - Water requirements for consumption and vehicle cooling, neglecting cooling for lunar environment, shall be on board at earth launch. Weights are included in the environmental control system.

9.1.7 First aid equipment. - The LEM shall be equipped with first aid and preventive medicine items for coping with various human injuries and disorders.

9.1.8 Weights. - The crew system weights are given in Table 3.

TABLE 3.- CREW + EQUIPMENT SYSTEM WEIGHT

Description	Weight (lb.)
Crew (2)	384
Spacesuit, helmet, boots (2 sets)	50
Seat (2)	10
Food	6
First aid	5
TOTAL CREW + EQUIPMENT	455

For radiation protection see Table 4 and Appendix C.

9.2 Structural system. - In addition to the fundamental load carrying structures, the LEM structural system shall include meteoroid protection, radiation protection and passive heat protection inherent in the structure. Primary structures shall be designed and evaluated in accordance with standard aircraft practice with the exception that no structure shall require pressure stabilization.

9.2.1 Pressure cabin. - The pressure cabin is of aluminum sandwich construction. The outer skin acts as a meteoroid bumper, the insulation is between the skins and the inner skin is the pressure vessel. Stringers and rings are disposed to act as edge members at all hatches and windows. Meteoroid protection over windows is included in the structural weights. The conical cabin has 8 windows totaling 29 square feet. The upper hatch has two windows totaling 1 square foot. Window area and orientation are the subject of further investigation.

9.2.2 Internal cabin structure. - The internal cabin structure distributes loads from the crew and on board equipment to the pressure cabin skins. Thrust loads from the engine are transmitted to the lower skins of the pressure vessel through the internal cabin structure.

9.2.3 Lunar launch stage structure. - The lunar launch stage structure introduces lunar launch thrust loads into the internal cabin structure, distributes loads to launch tankage and lower conical apron of the launch stage. It distributes launch stage loads to the landing stage structure in the stowed and landing configuration.

9.2.4 Lunar landing stage structure. - The lunar landing stage structure distributes landing gear loads to the basic structure. It provides the mechanical face and attachments for the launch stage. It provides the structural elements for attachment to the adapter rails. Micro meteroids bumper and insulation blankets are included.

9.2.5 Structural weights. - The structural weights are given in Tables 4, 5, and 6.

[redacted]

TABLE 4. - STRUCTURE SYSTEM WEIGHT LEM PAYLOAD

Description	Weight (lb.)
Upper hatch	12
Upper hatch windows (2)	4
Ring-upper hatch	5
Conical section shell	165
*Conical section windows (8)	92
Lower spherical press. V.	67
Stringers	7
Internal beams	44
LEM PAYLOAD STRUCTURE TOTAL	396

* Includes 12.6 lb/man lucite for radiation protection-Appendix C.

[redacted]

TABLE 5. - STRUCTURE SYSTEM WEIGHT LIFTOFF STAGE

Description	Weight (lb)
Conical section	90
Thrust support	25
Inner shell	46
Helium tank (2)	192
Fuel tank	56
Oxidizer tank	70
TOTAL LIFTOFF STRUCTURE	479

TABLE 6. - STRUCTURE SYSTEM WEIGHT LANDING STAGE

Description	Weight (lb)
Top shell	53
Bottom shell	74
Top outer shell	50
Outer cone	179
Inner cone	110
Helium tank (6)	890
Fuel tank	266
Oxidizer tank	348
TOTAL LANDING STAGE STRUCTURE	1970

9.3 Guidance and control system. - The concept of a lunar excursion module landing and returning for a lunar orbit rendezvous imposes the following requirements on the control and guidance system of LEM.

a. Control of de-orbit impulse to follow planned trajectories.
b. Braking, hovering and translation control to select the most desirable landing point.
c. Lunar launch guidance to rendezvous with the parent vehicle.
d. Docking with the parent vehicle.
e. Providing abort guidance and control during all phases.

9.3.1 Description. - The guidance and control system is essentially divided into three systems: the guidance system, the stabilization and control system, and a backup system. Provisions for both manual and automatic modes of control with pilot override are included.

9.3.2 The guidance system. - The guidance system is similar to the guidance system in the Apollo command module thus insuring that the spacecraft in lunar orbit and/or the LEM can direct the maneuvers for lunar rendezvous. Since the LEM has no requirement for atmospheric reentry guidance there is some simplification and modification of the system.

9.3.2.1 The inertial measurement unit. - The IMU can be the same as the one used in the Command Module. The IMU would consist of a three gimbaled unit using 25 IRIG gyros and 16 PIP accelerometers as the inertial elements. The gyros are considered to have the following errors:

Bias drift	10 Meru
Acceleration-sensitive drift due to acceleration along input axis	10 Meru/g
Acceleration squared-sensitive drift terms about the input axis	1 Meru/g^2
About the spin reference axis	1 Meru/g^2

The accelerometers are considered to have the following errors:

Acceleration bias	.20 m/rec^2
Scale factor error	100 ppm
Accelerometer sensitive error	1 ppm/g

These errors are valid for trajectory error analysis.

9.3.2.2 Computer. - The computer will have the same capability as the command module computer providing interchangeability of parts for redundancy considerations. It is anticipated that the main engine will be under the control of the computer during critical times such as retrofiring and lunar take-off.

9.3.2.3 Displays. - The minimum display requirements are as follows: attitude rates, attitude, rate of descent, altitude, forward velocity, lateral velocity, elapsed time, and control system pressures. The information will come from rate gyros, the IMU, computer, radar, and doppler systems. Display accuracy for elapsed time is $\pm$ .01 percent. Display accuracies for remaining display units should be $\pm$ 2 percent.

9.3.2.4 Optical device. - The optical device would be of about 30 power, with a two degree field of view. Readout accuracy should be within $\pm$ 1 arc second and have an illuminated scale.

9.3.3 Stabilization and control. - This system on the LEM provides attitude orientation, stability augmentation, and translational capability during free LEM flight, thrusting, hovering, vernier corrections for docking, lunar landing and lunar orbit rendezvous maneuvers. The control system provides the pilot with the ability to control six degrees of freedom.

9.3.3.1 Reaction control electronics. - Reaction-control electronics will be of the pulse ratio modulated type that allow astronaut adjustment of the attitude dead-band from $\pm 0.5^\circ$ to $\pm 10^\circ$ during the coast phase and thereby providing a maximum fuel economy limit cycle. Operation of the main engine automatically narrows the attitude dead-band to give high-torque operation to accurately control the thrust vector.

9.3.3.2 Manual controls. - Manual controls will include a pilot stick to effect rotation of the vehicle in pitch and roll, foot pedals to provide yaw control, and an additional stick with thumb buttons to provide translational movements.

9.3.3.3 Modes of operation. - In the normal mode of operation, attitude signals are received from the navigation and guidance system and by means of the reaction-control electronics, the thrusters are operated to give the desired orientation.

In the manual mode, control will be exercised by a redundant rate-command system using the same control electronics used in the automatic mode. Three body-mounted wide-angle rate-integrating gyros and a small electronics package will be added to the system. In normal operation the gyro would be torqued directly by the output from the manual control. The gyro now acts as a precision rate gyro feedback and results in a precision rate-command system. Release of the controls automatically puts the system in an attitude-hold condition at the new position. An attitude-command system is included by which capsule orientation can be "dialed" in. This is the preferred method of attitude control when one crew member only is available for the docking phase.

9.3.4 Backup guidance. - The choice of rate-integrating gyros for attitude hold provides the capability of accurate control of the thrust vector if failure of the inertial platform occurs. The addition of a longitudinal integrating accelerometer to the system can provide basic information which (in conjunction with the voice-link with the CM) provides back-up guidance.

9.3.5 Weights and power requirements. - The weights, power requirements, hours in use before lift off and after lift off are noted in Table No. 7.

 [redacted]

TABLE 7. - GUIDANCE AND CONTROL SYSTEM WEIGHT POWER, HOURS OF USE

Description	Weight (lb.)	Power Watts	Hours of use	
			Before Liftoff	After Liftoff
Inertial measurement unit	60	100	4	12
Optical measurement unit	30	2	4	12
Computer	36	80	4	12
Displays	12	10	4	12
Electronics	32	10	4	12
Cabling	12			
Range drift measurement unit	30	2	4	12
Visual line of sight	5	2	4	12
Guidance total	217	206	28	84
Attitude reference	12	2	4	12
Rate gyros	10	25	4	12
Control electronics	32	20	4	12
Manual controls	12			
Stabilization total	66	47	12	36
Strapdown inertial elements	5			
Displays	10			
Cabling	5			
Backup guidance total	20			
Total guidance and stabilization	303	253	40	120

[redacted]

9.4 Communication system. - The onboard communication system shall provide reliable voice communication, telemetry, direct real time television from the lunar surface, and a radar for rendezvous and lunar landing.

9.4.1 Voice communication. - This subsystem shall provide voice communication capabilities as follows:

a. Between the crew members within or outside the LEM.
b. Between a crew member within the LEM and one on the lunar surface.
c. Between the LEM and the Apollo Command Module while in line-of-sight of each other.
d. Between the LEM and the earth, and hence to the Apollo Command Module using the earth as a relay station to extend the range of the communication link between the LEM and Command Module.

9.4.1.1 Intercommunication system. - An intercommunication system shall be provided for voice communication between onboard crew members in space suits, for control of communication modes and for routing of voice and data to and from the various transceivers.

9.4.1.2 Two-way voice communication. - Two-way voice communication between the LEM and the Apollo command module shall make use of a VHF transceiver, a 20-watt power amplifier and a dipole antenna system.

9.4.1.3 LEM-to-earth voice link. - The LEM-to-earth voice-link will utilize a 2 kmc DSIF transponder operating in the transceiver mode, a 25-watt amplitron and a five-foot parabolic antenna erected on the lunar surface. The inflight version of this link makes use of a one-foot extendable parabolic antenna.

9.4.1.4 Personal communication. - Crew members will wear personal communication transceivers which operate in conjunction with an onboard VHF transceiver.

9.4.2 Telemetry. - All telemetry data transmission is either time shared with the voice or transmitted simultaneously with voice by using subcarriers within and below the voice frequency spectrum. Continuous data will make use of those channels below the audio range to prevent mutual interference between data and voice. Data transmission will be held to the minimum required for monitoring the condition of the crew and vital systems. All transmitters and receivers will have the capability of transmitting or relaying data.

9.4.3 Television. - Real time near commercial quality television shall be transmitted from the lunar surface to earth. Television information shall be phase-modulated directly on the 2 kmc carrier and transmitted by means of the same 25-watt amplifier and five-foot parabolic antenna which are used for the voice-link on a time-shared basis.

9.4.3.1 Quality. - Both vertical and horizontal resolution shall approximately 70 percent of commercial quality. Frame rate shall be minimum which will reproduce motion satisfactorily to the human eye (approx. 7.5 frames per sec.). Flicker effects shall be ignored since they can be greatly minimized by ground processing. Video bandwidth shall be approximately 500 kc.

9.4.3.2 Synchronization. - Line and frame synchronization shall be derived from a precision crystal controlled oscillator. Synchronization will be transmitted in the form of a carrier also derived from the same crystal oscillator.

9.4.4 Radar. - A radar system shall be provided for rendezvous guidance and as a lunar landing aid. This system shall be an X-band ICW radar using a one-foot multiple beam antenna.

9.4.4.1 Lunar landing mode altitude. - In the lunar landing mode altitude shall be measured within 5 ft. from 0 to 1000 ft. and within 50 ft. from 1000 ft. to 100 nautical miles. Vertical and horizontal velocities shall be measured from 0 to 3000 ft. per sec. with an accuracy of 1.0 percent or one foot per sec. whichever is the greater.

9.4.4.2 Rendezvous mode range measurement. - In the rendezvous mode range measurements conform to the same specifications as altitude measurements (above). Range rate shall be measured from 0 to 5000 ft. per sec. with the same accuracy as horizontal and vertical velocities.

9.4.5 Jettisonable items. - The low powered transceiver, the television system and the five-foot parabolic antenna shall be left on the lunar surface.

9.4.6 Weights and powers. - Communication system weights, powers and hours of use are given in Table 8.

[redacted]

TABLE 8.- COMMUNICATIONS SYSTEM WEIGHT, POWER, HOURS OF USE, AND WATT-HOURS

Description		Before Liftoff				After Liftoff				Requirements for Additional 24 Hours		
		Weight	Power	Hours in use	Watt-hours	Weight	Power	Hours in use	Watt-hours	Power	Hours in use	Watt-hours
Intercom	(1)	5	5	24	120	5	5	5	25	5	24	120
Personal comm. transceiver	(1)	3	3	20	120							
Personal comm. belt packs	(1)	4	4			4						
VHF antenna	(2)	1	1			1						
VHF transceiver	(1)	10	50 max 20 ave	24	480	10	50 max 20 ave	5	100	50 max 20 ave	24	480
2 KMC transceiver with 25 watt amplifier	(1)	35	100	24	2400	35		5	500	100	24	2400
Parabolic antenna (5 foot)	(1)	30					100					
Direct television	(1)	30	100	1	100							
Radar system	(1)	50	80	7	560	50	80	5	400			
Parabolic antennas (1 foot)	(2)	30				30						
Cabling		35				35						
TOTALS		233			3780	170			1025			3000

[redacted]

9.5 Environmental control system. - The environmental control system provides the conditioned atmosphere for life support from two separate recirculating system as follows:

a. Extravehicular suit environmental control system at 3.5 psia
b. Cabin environmental control system at 5 psia (figure 8).

Additional subsystem design criteria are given below:

9.5.1 Subsystem criteria. - These criteria are in addition to those listed in Section 7.0 and are applicable to the chosen subsystems.

Electrical heat load = .229 KW
Water vapor removal = 9.6 lb/man day
Suit leakage - The suit leakage is to be considered as 200 cc/min at STP.
Cabin leakage - The cabin leakage is to be considered as .2 pounds/hour at 5 psia.
Extravehicular suit environmental control system is to be considered for emergency operation during lunar rendezvous maneuvers.

9.5.2 Extra vehicular suit environmental control system. - The extravehicular suit environmental control system shall be capable of 4 hours untethered life support for lunar exploration, with recharging capability. Table 10 contains the weights of the components of the extra vehicular suit environmental control system.

9.5.3 Cabin environmental control system. - This system will provide a "shirt sleeve" environment in the manned compartment and sufficient ventilation flow to maintain comfort for the pressure suited crew. This configuration enables the crew to open their face plates and remove gloves for increased dexterity. In the event of decompression the crew can "button up" connect the suit bypass, and continue operation unimpeded.

9.5.4 Oxygen supply. - The oxygen supply for both systems will be stored such that requirements for the lunar landing and lunar stay time will be located in the landing stage while the requirements for launch and rendezvous will be stowed in the launch stage of the LEM. The oxygen supply will be stored supercritically in sufficient quantity to provide 7 days boiloff at 1 percent per day, four cabin repressurizations and a 50 percent reserve.

9.5.5 Carbon dioxide and odor control. - Carbon dioxide and odor control will be provided by LIOH and activated charcoal. The equipment required for the mission will be stored in the launch stage with the used LIOH and activated charcoal jettisoned at lunar launch.

9.5.6 Crew comfort. - Crew comfort is maintained by a regenerative heat exchanger and flow diverter valves. Circulation is provided by constant flow redundant blowers. Metabolic cooling and water condensation is accomplished by a water evaporative heat exchanger and centrifugal water separator. All water collected is available for cooling purposes.

9.5.7 Power requirements. - The power requirements of the environmental control system are as follows:

Suit blower + heater = 27.2 watts continuous 24 hour service must be supplied by 4 hour duration battery.
Cabin blower + heater = 64.2 watts continuous 36 hour service.
Cabin repressurization = 4 times at 22 minutes each 400 watts.

NOTE: During repressurizations there are no other ECS cabin power requirements.

9.5.8 Mission requirements. - The environmental control system shall provide 2 men life support for the 48 hour mission including 12 hour/man extravehicular suit operation, and sufficient oxygen to repressurize the cabin four times. Twenty hours of cabin operation and 4 hours/man of suit operation shall be available at lunar launch.

9.5.9 Weights. - The environmental control system weights are given in Table 9.

TABLE 9. - ENVIRONMENTAL CONTROL SYSTEM

Description	Landing wt.	In landing stage left on lunar surface	Liftoff
Loaded back pack (2)	72.38		72.38
Back pack expendables	35.13	35.13	
O_2 tankage	29.10	19.90	9.20
H_2O tankage	28.15	14.55	13.60
Regenerative heat exchange	10.00		10.00
H_2O evaporative heat exchange	15.00		15.00
Blowers	20.00		20.00
H_2O separator	5.00		5.00
Debris trap	2.00		2.00
Inverter	10.00		10.00
Plumbing, et cetera	50.00		50.00
O_2 + 50 percent	53.59	36.89	16.70
Cooling H_2O + 10 percent	66.00	31.40	34.60
LIOH + charcoal + 50 percent	24.48	8.16	16.32
Drinking H_2O + 15 percent	61.49	32.09	29.40
TOTAL SYSTEM	482.32	178.12	304.20

TABLE 10. - ENVIRONMENTAL CONTROL SYSTEM
EXTRAVEHICULAR SUIT (BACK PACK)

Description	Weight (lb)	Weight left in landing stage on lunar surface
Oxygen tankage (100 percent O_2)	0.77	
Cooling H_2O tankage (50 percent H_2O)	1.11	
Heat exchanger	3.00	
H_2O separator	3.00	
Valves + controls	5.00	
Heater + expulsion apparatus	3.00	
Inverter	3.00	
Debris trap	0.50	
Blower	2.00	
Back pack container + accessories	5.00	
Miscellaneous	1.00	
TOTAL BACK PACK (DRY)	27.38	
Oxygen + 50 percent reserve	0.77	0.77
Cooling H_2O + 75 percent reserve	2.22	2.22
LIOH + charcoal + 50 percent reserve	1.25	1.25
Batteries	4.57	4.57
TOTAL BACK PACK EXPENDABLES	8.81	8.81
TOTAL LOADED BACK PACK	36.19	

2 packs 72.38 lb. for liftoff.

Expendables for two packs - used or left on lunar surface = 4 x 8.81 = 35.24 lbs.

9.6 Electrical power and distribution. - The electrical power and distribution system shall supply, regulate and distribute all electrical power required by the LEM for the duration of the mission. The source of electrical power will be silver-zinc primary batteries. The batteries required from lunar liftoff to rendezvous with the CM and SM will be stored in the launch stage while those required from separation to liftoff will be stowed in the landing stage.

9.6.1 Weights and power usage. - The electrical power and distribution system weights are given in Table 11. An estimated power profile is shown in Figure 9.

9.7 Reaction control. - The LEM reaction control system shall be similar to the system in the command module. There are two independent interconnectable systems, each capable of meeting the total torque and propellant storage requirements. Each system consists of Helium pressurization, propellant storage, distribution and thrust chamber subsystems. A schematic of the systems is shown in Figure 10.

9.7.1 Weights. - The weights of the reaction control systems are given in Table 12.

TABLE 11. - ELECTRICAL POWER SYSTEM

Description	Before liftoff			After liftoff		
	Watts	Hours	Watt hours	Watts	Hours	Watt hours
ECS	64	24	1536	64	24	1536
Cabin repressurization	414	1	414			4025
Communication	150	27	3680	168	24	3036
TV	100	1	100			
Guidance and control	253	4	1012	253	12	
Power losses 20 percent			1348			1592
TOTAL	981		8080	485		9554

Battery weight 25 lb/KWH	Weight (lb)	Power requirement (KWH)
After liftoff	258	9.6
Before liftoff	213	8.1
TOTAL	471	17.7

TABLE 12. - REACTION CONTROL SYSTEM WEIGHT

Description	Weight (lb.)
Thrusters	15
Tankage	26
Plumbing + valves	9
Total inert system	50
Propellant	100
TOTAL REACTION CONTROL SYSTEM	150

9.8 Scientific payload. - The scientific payload is considered in detail in Appendix B. Equipment for scientific experiments will be stowed in the landing stage of the LEM the return payload will be stowed by the crew in the LEM cabin in a manned most advantageous for balance considerations.

9.8.1 Weights and volumes. - The payload weights and volumes are given in Table 13.

TABLE 13. - SCIENTIFIC PAYLOAD WEIGHT VOLUMES

Description	Weights lbs.		Volume cu. ft.	
	Landing	Liftoff	Landing	Liftoff
Radioactivity survey	10		0.15	
Temperature measurement	6			
Surface + rock form. detail	15			
Rock survey	1		0.01	
Communication	10		1.0	
Rock + soil analysis	10		1.0	
Friction	4		0.15	
Survey density	5		0.08	
Core sample	25		1.5	
Seismograph study	40		2.0	
Atmosphere study	27		1.9	
Gravity	5		0.15	
Magnetic field	7		0.4	
Sample containers	10	10	1.5	1.5
Samples		50		
Record + photographs	20	20	1.5	1.5
Film processing equipment	10			
High speed camera	10		1.0	
TOTAL SCIENTIFIC PAYLOAD	215	80	13.44	3.0

9.9 Landing system. - The landing system includes the lunar landing aids, load attenuation and launch support.

9.9.1 Lunar landing aids. - Penetrometers are deployed at the initial hover altitude and are distributed in a controlled pattern over the landing area. The signals returned to the LEM give:

a. Impact acceleration - time presentation on the oscilloscope with memory.

b. An integration of acceleration time over the first .010 seconds of impact. These are used by the flight crew to indicate a go-no-go landing surface.

9.9.2 Load attenuation. - The landing gear is designed using crushable structure shock struts for energy dissipation. The landing pads are designed using a low density crushable structure beyond half the radius and below half the depth for local impact attenuation.

9.9.3 Landing stability. - Landing and post-landing stability is achieved by gravity acting on the LEM inside a four point landing gear.

9.9.4 Gear stowing. - The landing gear is stowed in the earth launch configuration by effectively shortening the tower struts and allowing the gear to protrude between the cylindrical elements of the S IV B stage instrument package.

9.9.5 Landing system weights. - The landing system weights are given in Table 14.

TABLE 14. - LANDING GEAR SYSTEM WEIGHT

Description	Weight (lbs)
Strut (4)	181
V Strut (4)	277
Pads (4)	109
TOTAL LANDING GEAR SYSTEM	567

9.10 Propulsion system. - The propulsion system is a partially staged system which utilizes a single pressure-fed thrust chamber, propellant and pressurization tankage required for landing, and propellant and pressurization tankage required for launch from the lunar surface. Thrust vector control is accomplished by a separate reaction control system.

9.10.1 Thrust chamber. - The thrust chamber is a ablative cooled chamber and nozzle. It has a nozzle expansion ratio of 40:1 and produces a vacuum thrust of 8,600 lbs. at a chamber pressure of 150 psia. An 80 percent bell is used for nozzle extension. The specific impulse is estimated to be 305 lb. sec/lb. minimum. The throttling range of 8:1 is achieved through the use of a variable area injector.

9.10.2 Propellants. - The LEM propulsion system shall use N_2O_4 oxidizer and MMH or a mixture of 50 percent hydrazine (N_2H_4) and 50 percent unsymmetrical dimethylhydrazine (UDMH) fuel. If necessary N 0 will be added to depress the freezing point of N_2O_4.

9.10.3 Controls and accessories. - The schematic shown in Figure II indicates the normal system accessories. The following points should be considered in the design.

a. Filters are to be placed upstream of all critical central points.
b. Helium is stored in flight prior to initial use by using hand operated gate valves and caps at the charging points and normally closed parallel redundant squib valves at the outlet.
c. Propellants are stored in flight prior to initial use by using hand operated gate valves at the charging points and rupture diaphragms at the outlets.
d. Burst disc hardware is to be designed such that lines need not be disconnected for installation rather the diaphragm is to be installed in a rigid fitting.
e. Plumbing harness fittings are to be welded or brazed.
f. Filters are installed upstream of relief valves.

9.10.4 System operation. - The following points are to be considered for systems operation.

9.10.4.1 Pressurization system. - A gaseous helium pressurization system is used for supplying pressure to the propellant feed systems. Helium gas for this purpose is stored at 4,000 psia and is sealed in its tanks prior to system activation by squib valves. Redundant squib valves are provided in both tankage systems against valve failure to open. A filter downstream of these squib valves precludes any valve particles from contaminating downstream regulators and valves. The pressure regulator is designed to maintain and propellant tank pressure of 250 psia while the helium tank pressure varies from 4000 psia to 350 psia. This is based on a pressure drop of 100 psia across the regulator. Fail-safe operation in the event of regulator failure in the open mode is provided through redundant series regulators. Fail-safe operation in the event of regulator failure in the closed mode is provided through the redundant parallel regulator.

Check valves are of series-parallel configuration contained in one body. These valves prevent any possible oxidizer-fuel cross flow. Redundancy against leakage or failure to open is provided.

Relief valves in series with burst discs are installed near the propellant tanks inlets to prevent any over pressure condition in the propellant tanks. The burst discs provide a positive seal prior to any pressure surges thereby precluding possible leakage through the relief valve.

Test points are positioned throughout the system to permit preflight pressure checking of any part of the pressurization system. These points also allow each regulator to be checked under flowing conditions and allows emergency sequencing of the system solenoid valves. Helium tanks temperature and pressure instrumentation is indicated as well as manifold pressures prior to and following the regulating valving.

9.10.4.2 Propellant feed system. - The sealed tank concept used in the pressurization system during inflight storage prior to system use is applied to the oxidizer and fuel tanks in the propellant feed system. The check valves of the pressurization system act as a seal upstream of the tanks while burst discs are employed downstream of the tanks.

Dual propellant valves are the normal means of propellant shutoff at the chamber. Series-parallel redundant valves are used to insure ability to open a flow path into the thrust chamber. The fuel side and oxidizer side of these valves are mechanically connected so that they open and close in a fixed sequence. These valves are mounted on the injector to reduce ignition time. Operation signal for opening and closing these valves is supplied by the guidance system. Filters to protect these valves and the injector are located at the inlet to the valves.

Quick disconnects in combination with check valves are used for tank separation to facilitate staging. The disconnect couplings are self-sealing. To preclude overboard leakage, redundance is provided in series with each coupling. Quad check valves provide this redundance in the discharge lines of the fuel and oxidizer tanks.

Tank temperature and pressures and chamber temperature and pressure are provided for. Additional instrumentation may be desirable if control panels permit.

9.10.5 Propulsion system weights. - Propulsion system weights are shown in Tables 15, 16 and 17.

TABLE 15. - LIFTOFF INERT PROPULSION SYSTEM WEIGHT

Description	Weight (lb)
Thrust chamber	175
Electrical system	7
Components + lines	54
Pressurization comp. + lines	48
Residual helium	15
Residual propellant	45
Structure (Table 5)	479
TOTAL LIFTOFF INERT PROPULSION SYSTEM	823

TABLE 16. - LANDING STAGE INERT PROPULSION SYSTEM WEIGHT

Description	Weight (lb)
Comp. + lines	40
Pressurization comp. + lines	20
Residual helium	78
Residual propellant	148
Structure (Table 6)	1970
TOTAL LANDING STAGE INERT PROPULSION SYSTEM	2256

TABLE 17. - PROPULSION SYSTEM PROPELLANTS WEIGHTS

Description	Landing (lbs)	Liftoff (lbs)
LEM maximum	12913	3500
LEM 1 day + 1 day mission	12450	3500
LEM (less 5 percent ΔV)	11368	3274
LEM (less 25 percent growth)	11007	2962
LEM minimum	10060	2770

[redacted]

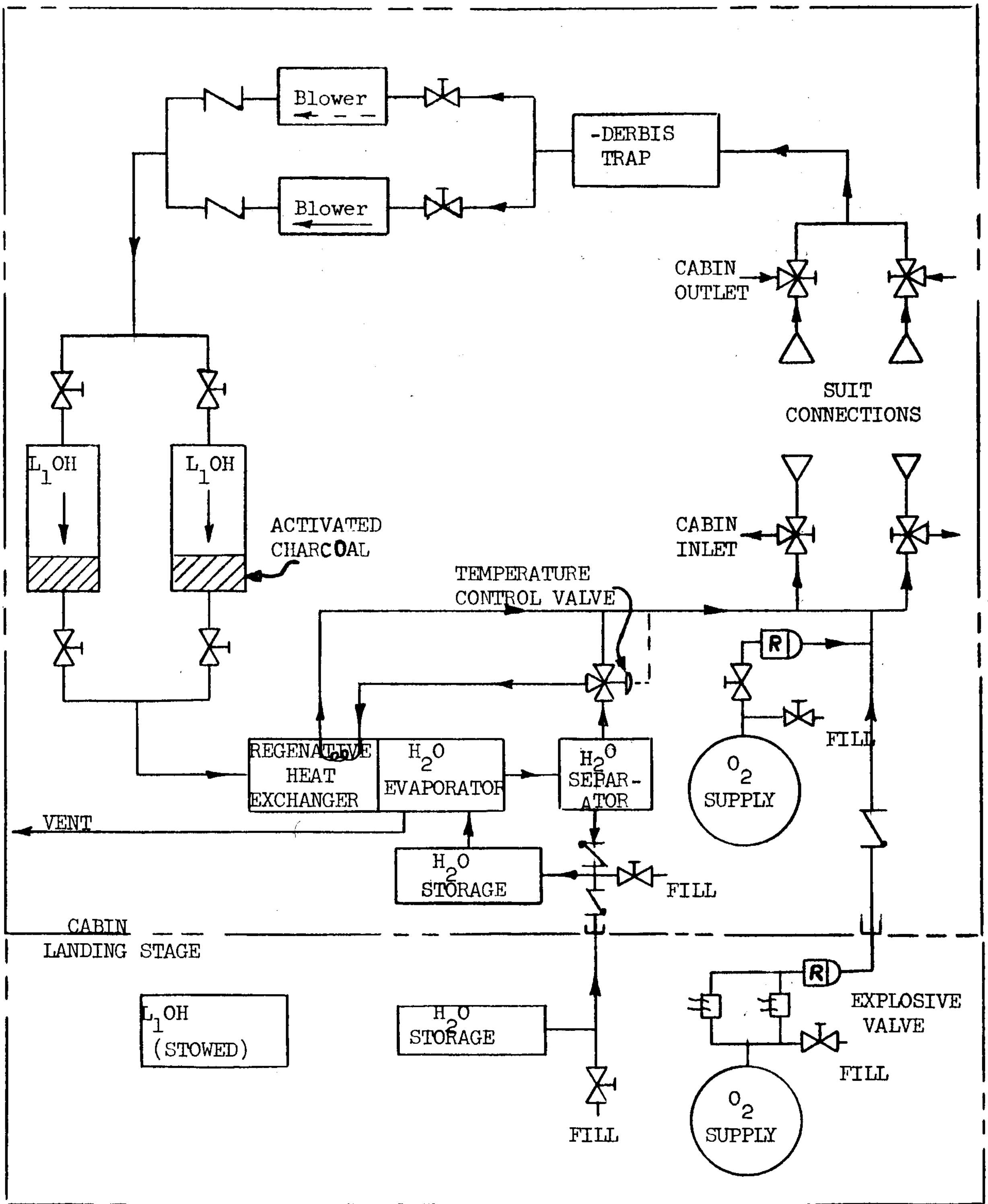


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FIGURE 7.- CABIN ENVIRONMENTAL CONTROL SYSTEM SCHEMATIC

[redacted]

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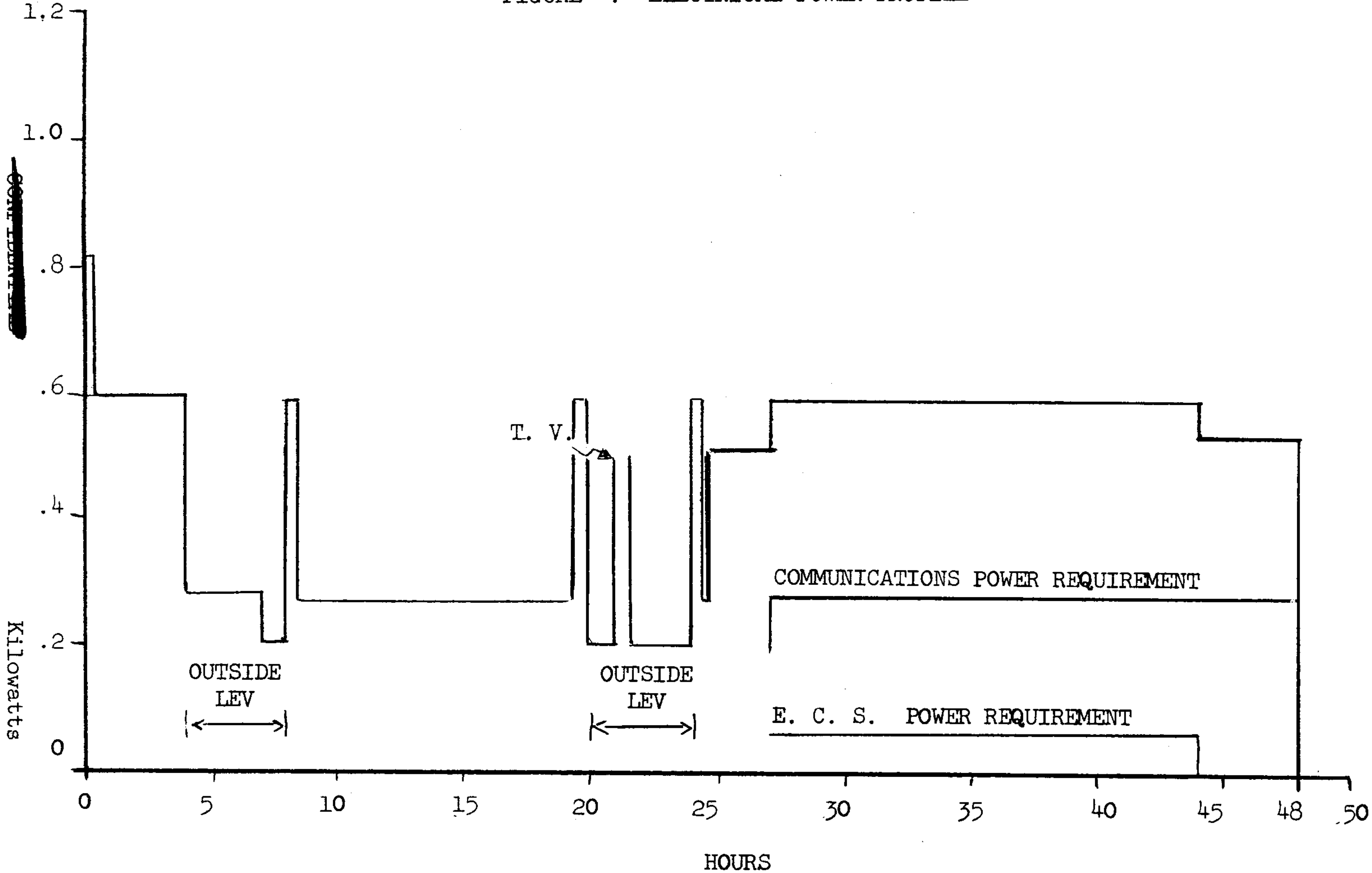
FIGURE 8.- ELECTRICAL POWER PROFILE



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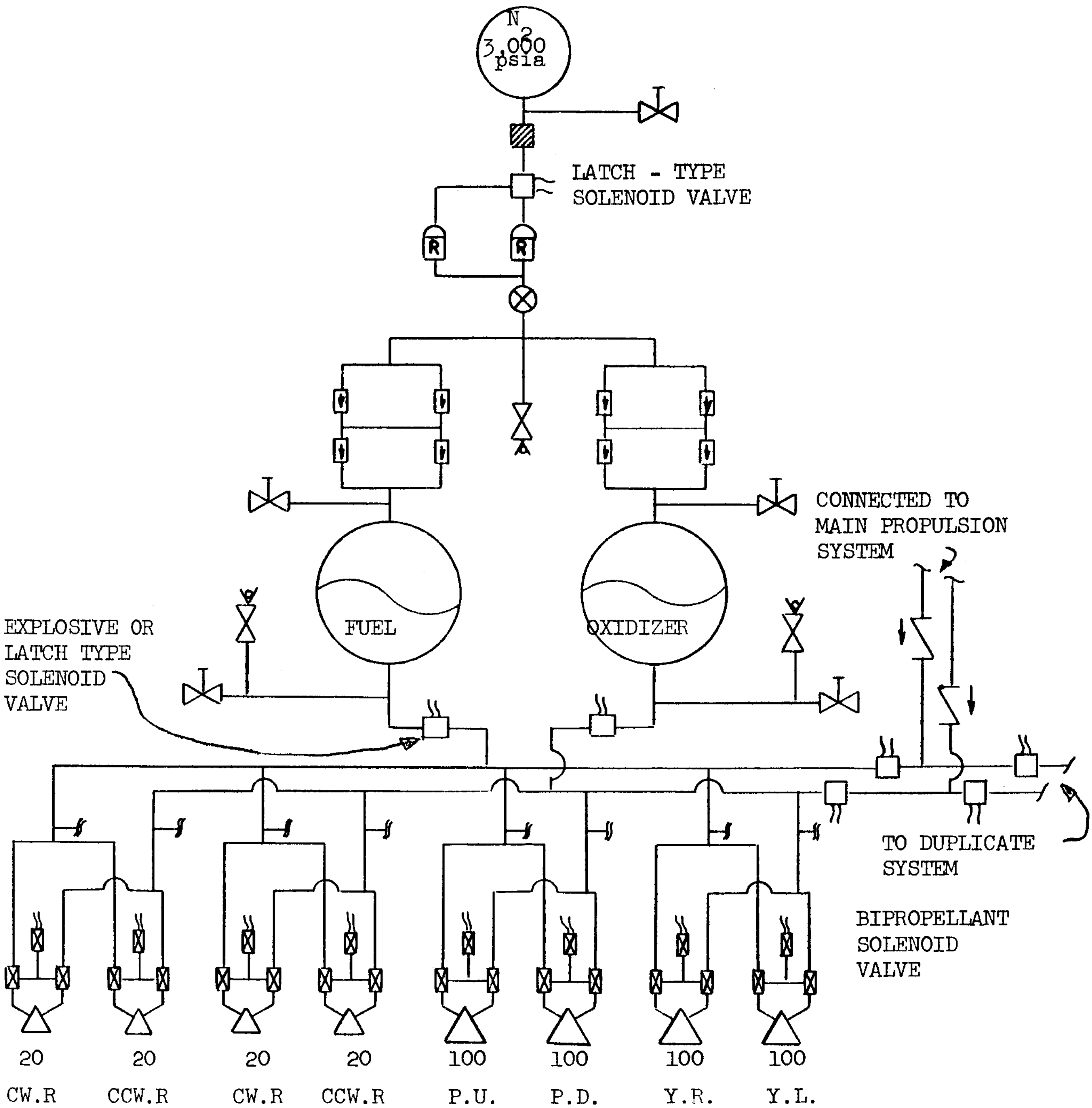

ADDITIONAL LOW LEVEL THRUSTERS TO BE CONSIDERED FOR TERMINAL MANUAL MODE.

FIGURE 9. - REACTION CONTROL SYSTEM SCHEMATIC

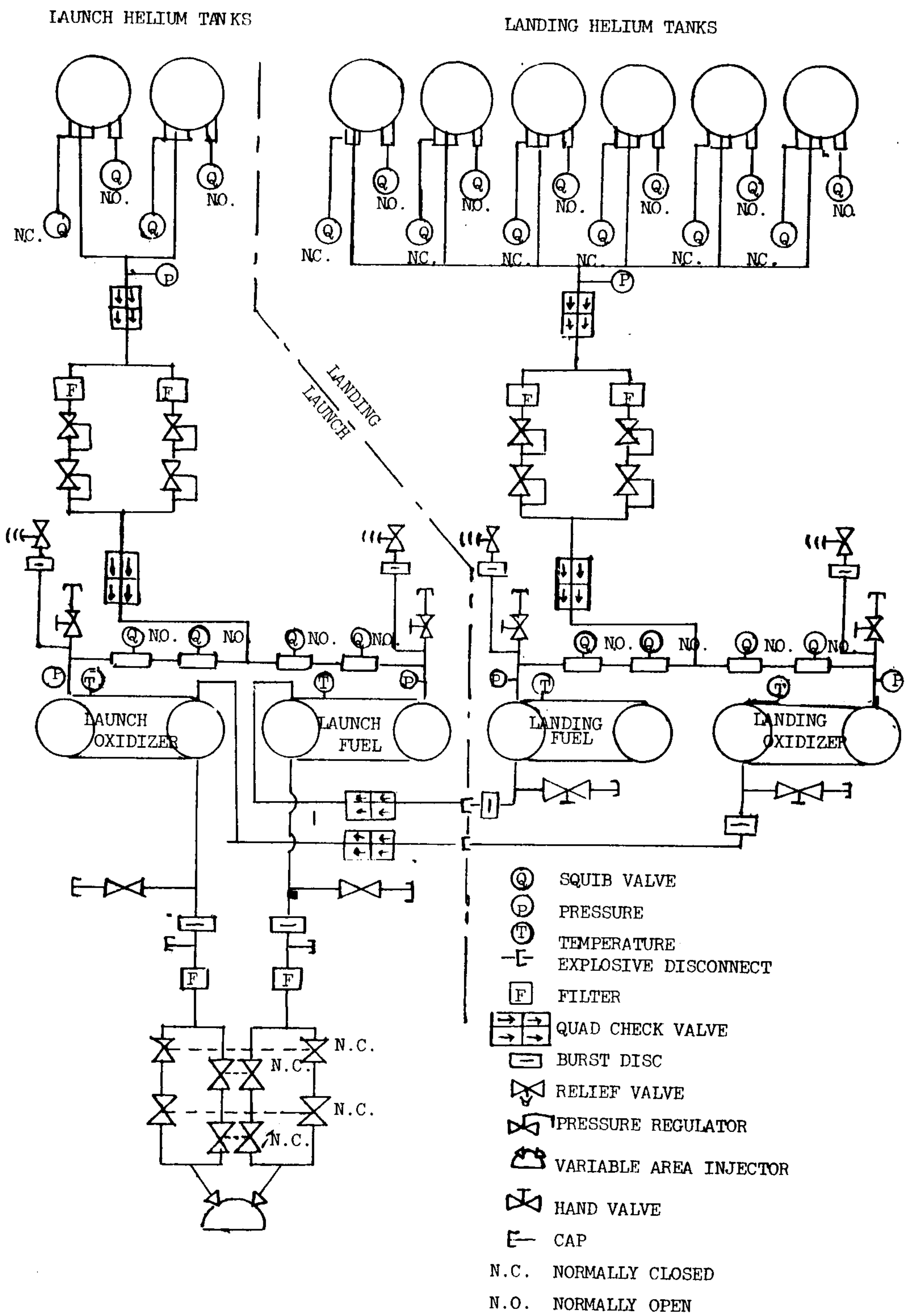

FIGURE 10. - LEM PROPULSION SYSTEM - PARTIALLY STAGED

10.0 WEIGHT AND BALANCE

10.1 <u>Weight breakdowns</u>.- Preliminary weight breakdowns for the LEM target and grown weights at major stages of the mission are given in Tables 18 through 23. The target weights for the command and service modules are given in Reference 3. The grown weights are obtained by adding 25 percent growth to the non-propulsive payload weight.

10.2 <u>Centers of gravity and mass moments of inertia</u>.- The reference axes for calculating of center of gravity and mass moment of inertia are shown in Figure 6. The values in Tables 24 through 27 are estimated and represent the best data available.

10.3 <u>Spacecraft weight history</u>.- Two sets of tables are included indicating variations in weight resulting from eliminating growth and ΔV margins (Tables 28 and 29).

[redacted]

TABLE 18.- SUMMARY WEIGHT STATEMENT LEM MAXIMUM WEIGHT

Description	Separation	Landing	Liftoff	Burnout
Payload	2745	2745	2745	2745
Launch inert propulsion	823	823	823	823
Launch propellant	3500	3500	3500	
Landing inert propulsion	2256	2256		
Landing propellant	12913			
Landing gear	567	567		
Landing aids	22			
Payload left on lunar surface	1133	1133		
TOTAL WEIGHT	23959	11024	7068	3568

[redacted]

TABLE 19.- SUMMARY WEIGHT STATEMENT LEM 1 DAY + 1 DAY MISSION

Description	Separation	Landing	Liftoff	Burnout
Payload	2745	2745	2745	2745
Launch inert propulsion	823	823	823	823
Launch propellant	3500	3500	3500	
Landing inert propulsion	2256	2256		
Landing propellant	12450			
Landing gear	567	567		
Landing aids	22			
Payload left on lunar surface	736	736		
TOTAL WEIGHT	23099	10627	7068	3568

TABLE 20. - SUMMARY WEIGHT STATEMENT LEM (ΔV LESS 5 PERCENT)

Description	Separation	Landing	Liftoff	Burnout
Payload	2,745	2,745	2,745	2,745
Launch inert propulsion	823	823	823	823
Launch propellant	3,274	3,274	3,274	
Landing inert propulsion	2,256	2,256		
Landing propellant	11,368			
Landing gear	567	567		
Landing aids	22			
Payload left on lunar surface	736	736		
TOTAL WEIGHT	21,791	10,401	6,842	3,568

TABLE 21. - SUMMARY WEIGHT STATEMENT LEM (LESS 25 PERCENT GROWTH)

Description	Separation	Landing	Liftoff	Burnout
Payload	2,196	2,196	2,196	2,196
Launch inert propulsion	823	823	823	823
Launch propellant	2,962	2,962	2,962	
Landing inert propulsion	2,256	2,256		
Landing propellant	11,007			
Landing gear	567	567		
Landing aids	22			
Payload left on lunar surface	589	589		
TOTAL WEIGHT	20,422	9,393	5,981	3,019

 [redacted]

TABLE 22.- SUMMARY WEIGHT STATEMENT LEM (LESS GROWTH AND 5 PERCENT ΔV)

Description	Separation	Landing	Liftoff	Burnout
Payload	2,196	2,196	2,196	2,196
Launch inert propulsion	823	823	823	823
Launch propellant	2,770	2,770	2,770	2,770
Landing inert propulsion	2,256	2,256		
Landing propellant	10,060			
Landing gear	567	567		
Landing aids	22			
Payload left on lunar surface	589	589		
TOTAL WEIGHT	19,283	9,201	5,789	3,019

TABLE 23.- PAYLOAD WEIGHT

Description	Landing Weight (lbs.)	Liftoff Weight (lbs.)
Crew and equipment	455	455
Structure	396	396
Guidance and control	303	303
Communications	233	170
Environmental control system	482	304
Electrical power system	471	258
Reaction control system	150	150
Instrument panel	80	80
Scientific payload	215	80
TOTAL PAYLOAD WEIGHT (No growth)	2,785	2,196
Contingency (25 percent)	696	549
TOTAL - PAYLOAD WEIGHT (With growth)	3,481	2,745

[redacted]

TABLE 24.- MAXIMUM WEIGHTS SPACECRAFT COMPONENTS LESS LEM

Item	Weights-lbs.	$\bar{X}$ In.	$\bar{Y}$ In.	$\bar{Z}$ In.	Roll I_{x-x} Slug Ft^2	Pitch I_{y-y} Slug Ft^2	Yaw I_{z-z} Slug Ft^2
Command module	10625	408.0	0	7.0	4980	4660	3950
Service module	43682	293.0	0	0	43948	23989	23989
Adapter	1450	125.0	0	0	908	1689	1689
Launch escape system	5000						

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TABLE 25.- MINIMUM WEIGHTS SPACECRAFT COMPONENTS LESS LEM

Item	Weight-Lbs.	$\overline{X}$ In.	$\overline{Y}$ In.	$\overline{Z}$ In.	Roll I_{x-x} Slug Ft^2	Pitch I_{y-y} Slug Ft^2	Yaw I_{z-z} Slug Ft^2
Command module	8500	408.0	0	7.0	3980	3720	3160
Service module	33758	293.0	0	0	35158	19191	19191
Adapter	1450	125.0	0	0	908	1689	1689
Launch escape system	5000						

[redacted]

TABLE 26.- MAXIMUM WEIGHTS LEM

Item	Weight-Lbs.	$\bar{X}$ In.	$\bar{Y}$ In.	$\bar{Z}$ In.	Roll I_{x-x} Slug Ft^2	Pitch I_{y-y} Slug Ft^2	Yaw I_{z-z} Slug Ft^2
Burnout weight	3568	0.15	0	60.9	732	755	560
Launch weight	7068	0.07	0	66.2	2425	2450	3825
Landing weight	11024	0.05	.58	91.6	6370	6230	5000
Separation weight	23959	0.02	.27	96.9	14750	14600	19800

[redacted]

TABLE 27. - MINIMUM WEIGHTS LEM

Item	Weight-Lbs.	$\overline{X}$ In.	$\overline{Y}$ In.	$\overline{Z}$ In.	Roll I_{x-x} Slug Ft^2	Pitch I_{y-y} Slug Ft^2	Yaw I_{z-z} Slug Ft^2
Burnout weight	3019	0.15	0	62.4	626	650	475
Launch weight	5789	0.09	0	66.8	1960	1980	3060
Landing weight	9201	0.06	.50	92.5	4890	4750	4340
Separation weight	19283	0.03	.24	97.2	11420	11280	15850

TABLE 28.- MISSION SUMMARY

	90,000 lb **ΔΔ	80,000 lb **ΔΔ	LEM Mission **ΔΔ
Non Propulsive Payload	13750	13750	13750
S.M. Propulsion Inert Weight	5899	5899	5899
Weight Returned to Vicinity of Earth	19649	19649	19649
Propellant Used from Lunar Orbit (Midcourse injection)	11007	11007	11007
Weight in Lunar Orbit after Rendezvous	30656	30656	30656
Weight of Crew Transferred from LEM	-558	-558	-558
Weight CM + SM in Lunar Orbit (During LEM Lunar Staytime)	30098	30098	30098
LEM Separation Weight	30771	23959	23099
Weight in Lunar Orbit Before Separation	60869	54057	53197
Propellant Used From Earth Escape Into Lunar Orbit	28481	25293	24891
Weight at Earth Escape	89350	79350	78088
LES Eff. Wt. (4 percent) and Adapter Mod. (400 lb)	650	650	650
Earth Escape Weight	90000	80000	78738
Weight of LEM Carried In Translunar Trajectory	30213	23401	22541
Weight of crew Transferred to LEM From CM	+558	+558	+558
Separation Weight of LEM	30771	23959	23099
Propellant Used in Landing	-16585	-12913	-12450
Landing Aids	-22	-22	-22
Landing Weight	14164	11024	10627
Landing Propulsion Inert Weight	-2256	-2256	-2256
Landing Gear Weight	-567	-567	-567
Equipment Left on Landing Stage	-736	-736	-736
Additional Payload Available	-3537	-397	----
Launch Weight	7068	7068	7068
Propellant Used on Launch and Rendezvous	-3500	-3500	-3500
Burnout Weight	3568	3568	3568
Inert Propellant System Launch Stage	-823	-823	-823
Payload to Lunar Orbit	2745	2745	2745

Δ Minimum Target Weight
ΔΔ Grown Weight
* ΔV Ref. Table 1
** ΔV + 5 percent Ref. Table 1

TABLE 28.- MISSION SUMMARY (Continued)

	LEM Mission *ΔΔ	LEM Mission **Δ.	LEM Mission *Δ
Non Propulsive Payload	13750	11000	11000
SM Propulsion Inert Weight	5899	5899	5899
Weight Return to Vicinity of Earth	19649	16899	16899
Propellant Used from Lunar Orbit (Midcourse Injection)	10365	9467	8914
Weight in Lunar Orbit after Rendezvous	30014	26366	25813
Weight of Crew Transferred from LEM	-558	-558	-558
Weight CM + SM in Lunar Orbit (During LEM Lunar Staytime)	29456	25808	25255
LEM Separation Weight	21791	20422	19283
Weight in Lunar Orbit Before Separation	51247	46230	44538
Propellant Used From Earth Escape Into Lunar Orbit	22610	21631	19650
Weight at Earth Escape	73857	67861	64188
LES Eff. Wt. (4 percent) and Adapter Mod. (400 lb)	650	650	650
Earth Escape Weight	74507	68511	64838
Weight of LEM Carried in Translunar Trajectory	21233	19864	18725
Weight of Crew Transferred to LEM from CM	+558	+558	+558
Separation Weight of LEM	21791	20422	19283
Propellant Used in Landing	-11368	-11007	-10060
Landing Aids	-22	-22	-22
Landing Weight	10401	9393	9201
Landing Propulsion Inert Weight	-2256	-2256	-2256
Landing Gear Weight	-567	-567	-567
Equipment Left on Landing Stage	-736	-589	-589
Additional Payload Available	----	----	----
Launch Weight	6842	5981	5789
Propellant Used on Launch and Rendezvous	-3274	-2962	-2770
Burnout Weight	3568	3019	3019
Inert Propellant System Launch Stage	-823	-823	-823
Payload to Lunar Orbit	2745	2196	2196

Δ Minimum Target Weight

ΔΔ Grown Weight

* ΔV Ref. Table 1

** ΔV + 5 percent Ref. Table 1

TABLE 29.- MISSION HISTORY

Description	LEM Mission (1) △	LEM Mission (2) **	LEM Mission (3) **	LEM Mission (4) *	LEM Mission (5) **	LEM Mission (6) *
Command Module	8500	8500	8500	8500	8500	8500
Command Module Growth (25 percent)	2125	2125	2125	2125		
TOTAL COMMAND MODULE	10625	10625	10625	10625	8500	8500
Service Module	2500	2500	2500	2500	2500	2500
Service Module Growth (25 percent)	625	625	625	625		
Service Module Inert Prop.	5899	5899	5899	5899	5899	5899
Service Module Prop.	39488	36300	35898	32975	31098	28564
TOTAL SERVICE MODULE	43682	45324	44922	41999	39497	36963
LEM Weight	30213	23401	22541	21233	19864	18725
Separation Wt.	30771	23959	23099	21791	20422	19283
Landing Wt.	14186	11024	10627	10401	9393	9201
Liftoff Wt.	7068	7068	7068	6842	5981	5789
Burnout Wt.	3568	3568	3568	3568	3019	3019
Adapter Wt.	400	400	400	400	400	400
LEPS (4 percent eff)	250	250	250	250	250	250
Payload to Lunar Surface	3537	1133	736	736	589	589
Earth Escape Weight	90000	80000	78738	74507	68511	64838

11.0 PROBLEM AREAS

The following problem areas have arisen during the preparation of this paper for review and are presented for further consideration.

Additional questions, problems and errors generated by reviewers should be reported to the Spacecraft Integration Branch.

1. How does the Lunar stay time vary with mission objectives?
2. How is exploration capability extended beyond immediate landing vicinity?
3. What are the problems associated with landing at various selenographic locations?
4. What are the abort techniques and programs for all mission stages?
5. What changes can be made in CM and SM if direct Lunar landing provisions are eliminated?
6. To what extent can LEM Guidance and Control System back up CM Guidance and Control Systems?
7. Could LEM cabin be returned to vicinity of earth? Advantages? Problems?
8. Can systems be designed using interchangeable components from one module to another (LEM to CM)?
9. What advantages, disadvantages and problems are caused by electrical power interface between CM and LEM?
10. What difficulties will be encountered with LEM checkout during translunar flight?
11. What are air lock operation procedures and hardware during translunar flight and rendezvous?
12. What are the problems associated with stabilizing the S IV B stage in the initial docking maneuver and also in making positive and permanent separation of this stage from the CM and SM?
13. What problems are involved with incorporating an air lock in LEM in upper or side hatch?
14. Are structural schematics required and to what degree?

15. What CG offset should be considered for Reaction Control System when considering toroidal or other tanks, variation in thrust vector, equipment offset, et cetera.

16. What number of hard points are required for attaching LEM to adapter?

17. How do number of hard points of question 16 influence number of landing gear legs?

18. What are docking impact loads? How do they vary with initial conditions and detail design?

19. What type of cooling is required for Reaction Control Thrusters?

20. What vehicle orientations are required on the translunar trajectory to maintain temperature control such that active systems are not compromised?

21. What temperature control technique should be employed for propulsion and other systems as a function of solar insolation on the lunar surface is required?

22. Are concentrated and distributed loads in longitudinal and lateral directions optimized to allow efficient utilization of onboard systems of spacecraft?

23. What are the communication requirements and capabilities for the time period between SM and CM afterbody jettisoning?

24. What optimization of the thrust and weight ratio for lunar landing hover, and liftoff all with the same engine is required?

25. How can the spacecraft reliability, performance and capabilities be enhanced by information from lunar reconnaissance missions? How can the spacecraft be used to obtain information ascertained to be required in answering the first part of the question?

26. How does off-loading of propellants in LEM landing stage influence CG travel and systems providing stabilization and attitude control?

27. What are the advantages of retaining the SM closer to reentry than 4 hours prior to reentry?

28. What problems arise to achieve selected earth-landing sites and to satisfactorily traverse radiation belts after abort initiated during early, mid, and final translunar injection phase?

29. Are provisions made in the detailed description of the extravehicular space suit, boots, and helmet to provide meteoroid protection on lunar surface and to prevent dust contamination when reentering the LEM cabin?

30. What problems are involved with obtaining reduced wattage and power usage?

31. What problems are developed in LEM window design to improve crew comfort, visibility, reduce glare, and provide meteoroid protection?

32. What problems involved in improving reliability, to space-qualify, and to reduce weight of electrical power sources?

33. What are the problems which arise when considering high impulse propellants for the LEM and SM?

34. What are the requirements for the radar altimeter?

35. What are the C-5 capabilities for payload to translunar injection for the several techniques of launch and injection?

36. How great a menace are sporadic meteroid showers to the successful completion of the mission?

37. What cabin leak rates should be used for design estimates?

38. What problems are encountered when improving pilot visibility so that he can see along the engine thrust line, particularly during the landing maneuver?

39. What problems are associated with free-flight docking?

40. What problems are associated with mechanical aids for docking?

41. What problems are developed when complete staging of LEM propulsion system is used.

42. Will an electrostatic discharge take place between two vehicles in space?

43. To what extent are spare parts required?

APPENDIX A

MISSION SEQUENCE

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APPENDIX A

TABLE OF CONTENTS

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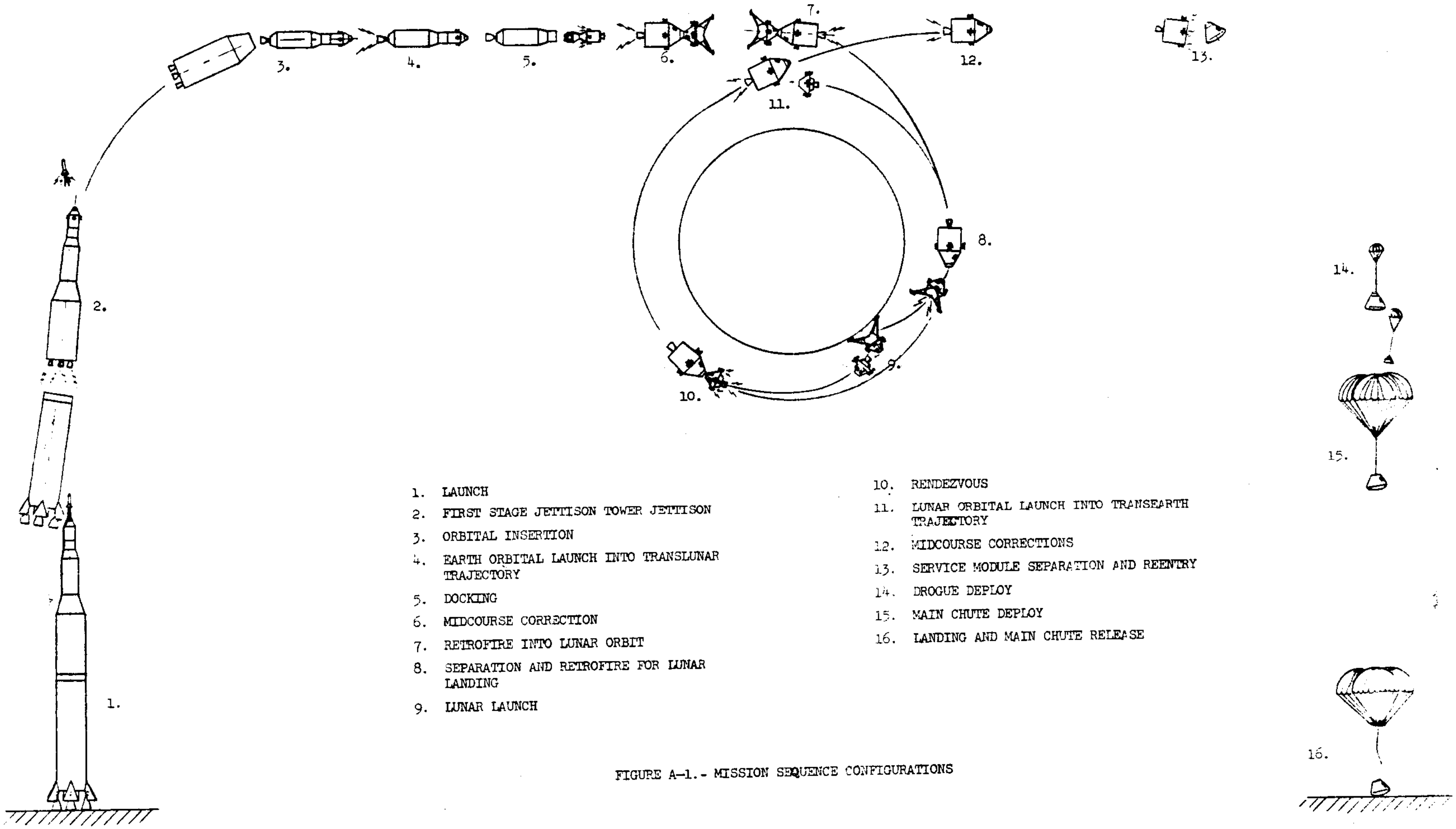


FIGURE A-1.- MISSION SEQUENCE CONFIGURATIONS

[redacted]

1. Introduction. - The mission sequence defines the mission operations to be performed during successive time intervals from crew entry into the spacecraft, prior to launch, to recovery after landing. A nominal earth-moon-earth trajectory utilizing earth and lunar orbital launch and rendezvous after lunar takeoff, shall be employed to determine interval time boundaries and midcourse correction initiation times.

2. CCMR. - Countdown, checkout, maintenance, and repair procedures are a systematic survey of the operating conditions of all onboard systems.

2.1 Countdown. - The countdown period encompasses all functions performed in the preparation for the execution of any major sequence event.

2.2 Checkout. - The checkout procedure involves the acceptance of all major systems operation as being in operational status.

2.3 Maintenance. - The maintenance operations are those of minor adjustments to forestall major malfunction of any system. Maintenance will generally be the preventive type.

2.4 Repair. - The repair functions are those functions correcting any damage or breakdown encountered during the mission.

3. Abort. - The abort sequence shall be possible in two distinct phases, (1) while all crew members are present in the (CM), and (2) while the two crew members are performing the landing and launch missions in the LEM.

3.1 Command module. - The crew have the option of terminating the mission at any time during flight from the earth to the moon.

3.1.1 Liftoff to translunar injection. - Abort during any of three intervals in this phase is relatively simple to effect, as no trajectory corrections other than those previously planned shall be required.

3.1.1.1 Prior to tower jettison. - Abort during this phase extends from a time prior to launch vehicle engine ignition until escape tower jettison. Abort will be accomplished by shutdown of the launch vehicle engines and separation of the CM from the SM following activation of the launch escape system.

3.1.1.2 Prior to orbital insertion. - This abort period shall start at escape tower jettison and continue until earth orbital insertion. Abort shall be accomplished by shutdown of the launch vehicle engines, separation of the CM and SM from the launch vehicle by use of SM propulsion system, and retro-firing of the SM reaction control thrusters.

3.1.1.3 Earth orbital phase. - This abort period shall start at earth orbital insertion and continue until initiation of translunar injection. Abort shall be accomplished by separating from the S IV B stage and orienting the vehicle for retro-fire using the SM reaction control system, retro-firing using the SM propulsion system, and separating the CM from the SM using the SM reaction control system. The time for abort initiation may then be random or as required by selected earth landing sites.

3.1.2 Translunar injection phase. - This phase shall start with initiation of injection from earth orbit and terminate with achievement of the translunar trajectory. Abort during this phase can be accomplished by shutdown of the S IV B stage engines, separating the CM/SM from the S IV B stage and orienting the vehicle for return using the SM reaction control system, and attaining return ΔV using the SM propulsion system. The crew may then select one of two options according to the preplanned procedure.

Direct entry. - Direct entry will normally be achievable early in the injection phase. This type of abort will be limited by the SM thrust and propellant capabilities and is particularly time critical.

Satisfactory earth landing sights and L/D capabilities for achievement must be considered. These constraints and others form a complex abort decision and capability network.

The SC will enter earth orbit and park until preplanned landing procedures can be accomplished. Final abort maneuvers will be accomplished by orienting the spacecraft for retrofiring using the SM reaction control system, retrofiring from earth orbit using the SM propulsion system, and separating the CM from the SM using the SM reaction control system.

3.1.3 Translunar flight. - This period begins with achievement of translunar trajectory and extend to lunar orbit.

3.1.3.1 Prior to Moon's sphere of influence. - Abort during this period may be accomplished with a direct return maneuver which is severely limited by the propulsion system and landing sight. The spacecraft will be oriented using the SM reaction control system and injected into an earth return flight using the SM propulsion system. The remainder of the return flight will proceed as in the normal transearth flight plan.

3.1.3.2 Prior to lunar orbit. - This period extends from the moon's sphere of influence to lunar orbit. Abort during this time shall be accomplished by circum-navigating the moon and entering the trans-earth trajectory. The mission will then be accomplished as normal from this point.

3.2 LEM. - The LEM is capable of abort at anytime from initiation of letdown maneuvers to lunar touchdown and a short period after touch-down. Each lunar orbit for the (CM-SM) offers an optimum abort period with abort launch windows depending on the performance margins required. Abort will be initiated by staging the LEM landing tankage, gear and equipment, and utilizing the thrust-attitude time programs to control the abort trajectories. Normal terminal rendezvous and docking procedures will be conducted to terminate the LEM mission in a free flying mate with the CM.

4. Prelaunch. - The prelaunch period extends from the time to crew entry into the spacecraft until launch vehicle engine ignition. The crew will have an active role in the prelaunch operations and the option of terminating the mission at any time.

4.1 CCMR. - The primary duty of the crew during the prelaunch period is the participation in the CCMR as outlined in Section 2.

5. 0-4 Hours: Earth launch to translunar injection. - This phase of the mission will deal with insertion of the spacecraft in a 300 nautical mile earth orbit, preparation of the spacecraft for trans-lunar flight, and translunar injection of the spacecraft.

5.1 Launch. - The launch phase begins at T=0 with launch vehicle engine ignition.

5.1.1 Power flight. - The powered flight will include the time from launch vehicle engine ignition to cutoff of the second stage engines of the launch vehicle prior to earth orbital insertion.

6. 4-76 Hours: Translunar injection to lunar orbit. - The translunar flight will involve all operations necessary to assure crew safety and to achieve the required lunar orbit.

6.1 Launch. - The launch phase will be initiated with ignition of the S IV B stage engines. Ignition will be accomplished either automatically or manually at a preplanned time.

6.1.1 Powered flight. - The powered flight phase will extend from S IV B stage engine ignition to shutoff. The S IV B propulsion will be capable of furnishing a ΔV of 11,100 feet per second to achieve injection on a translunar trajectory.

6.2 Coast phase. - The major portion of the coast phase activity shall be placed in five areas. The coast phase shall begin with the S IV B stage engine cutoff.

6.2.1 Trajectory checks. - Trajectory checks will be performed at 1.6 hour intervals, beginning at translunar flight injection, to determine flight path position and error accumulation.

6.2.2 LEM docking. - Immediately after passage through the outer radiation belt at approximately T = 5.8 lbs., the LEM docking and mating sequence will be initiated. This sequence will be completed one hour after initiation and approximately eleven hours before the first midcourse correction. During passage through the radiation belts the S IV B stage will be stabilized by its own reaction control system controlled from the command module. The S IV B stage will be stabilized in rate damping mode during the docking and mating sequence. The mating and docking will be accomplished by separating the CM/SM from the LEM/S IV B, rotating 180° to docking attitude, and docking using the SM reaction control system.

6.2.3 Staging. - Staging of the spacecraft after docking will be accomplished by backing the CM/SM/LEM combination away from the S IV B stage with the SM reaction control system.

6.2.4 Solar flare monitoring. - During the coast phase the crew will monitor onboard radiation detectors and maintain communication with earth stations to obtain information on the solar disc. This information will be evaluated onboard to determine if conditions constitute an abort situation. If abort is not advisable the crew will assume their flare duty stations protecting themselves with the appropriate partial body shielding.

6.2.5 Midcourse correction. - Midcourse corrections will be performed during translunar flight with a total accumulative ΔV of not greater than 500 feet per second. Midcourse maneuvers will be accomplished by orienting the spacecraft to the required thrust vector using the SM reaction control system and attaining the required ΔV using the SM propulsion system. Any plane change necessary during translunar flight will be accomplished at the moon's sphere of influence.

6.3 Lunar orbit. - The spacecraft is inserted into a 100 nautical mile circular equatorial lunar orbit. This orbit shall be achieved by orienting the spacecraft to retro-firing attitude using the SM reaction control system and retro-firing using the SM propulsion system. The propulsion system shall be capable of furnishing a ΔV up to 3225 feet per second to attain orbit.

6.3.1 CCMR. - The crew will perform a CCMR on the spacecraft and its systems, with special attention on the SM propulsion, prior to initiation of orbital insertion maneuvers.

7. 76-80 Hours: Lunar orbit to separation of LEM. - This interval will begin with lunar orbit and end with separation of the LEM from the CM. The primary crew function will be the final preparation

of the LEM for completion of the lunar landing mission.

7.1 Orbit analysis. - The spacecraft orbit shall be confirmed, all characteristics established, and any necessary adjustments made.

7.2 LEM preparation. - The complete CCMR of the LEM will be performed after final transfer of the crew to the LEM. Formal countdown procedures would be followed.

7.2.1 LEM separation. - The LEM will be separated to await transfer to elliptical orbit. Separation shall be achieved by applying a small ΔV increment using the LEM reaction control system.

8. 80-81 Hours: LEM separation to LEM elliptical orbit. - During this interval the LEM will transfer from circular spacecraft orbit to an elliptical orbit.

8.1 LEM. - The principle mission responsibility shall be centered in the LEM.

8.1.1 Powered flight. - The LEM crew will monitor systems performance and maintain constant communications with earth, and the CM when possible. The LEM propulsion will be capable of furnishing a total ΔV 120 feet per second to attain the desired elliptical orbit.

8.2 Command Module. - The Command Module will have a primarily passive role in the mission from this time until rendezvous with LEM, however, it will be maintained in readiness to provide backup to guidance and communications. It will observe and record the LEM's progress.

9. 81-87 Hours: LEM elliptical orbit to LEM lunar touchdown. - The principle duties of the LEM crew will be the control of the letdown maneuver to the pre-planned landing site, the selection of a touchdown control over the touchdown maneuver and the anticipation of abort procedures at all times.

9.1 LEM. - The principle workload will be in the LEM.

9.1.1 Orbit. - The LEM crew shall relay all orbital data to the CM for confirmation of orbital characteristics.

9.1.2 Lunar surface survey. - The LEM crew visually will survey the preselected landing sites and make the final selection prior to initiating letdown and landing maneuvers. The landing aids will be deployed and the information will be evaluated.

9.1.3 Lunar landing. - The lunar letdown and landing maneuver will be performed by the LEM crew beginning at retro-firing in orbit through letdown and hover, and terminating with touchdown on the lunar surface. The LEM propulsion system will be capable of furnishing up to 6724 feet per second ΔV to effect a satisfactory landing.

9.1.3.1 LEM letdown. - The letdown will be initiated by orienting the LEM in retro-fire attitude using the LEM reaction control system and retro-firing from elliptical orbit using the LEM propulsion system.

9.1.3.2 Hover and translation. - The LEM will hover above the lunar surface at an altitude of 500 feet and then translate as required up to 1000 feet using the throttled LEM propulsion system for support and reaction control system for stability and control until the final landing site has been located and reached.

9.1.3.3 Touchdown. - The LEM touchdown will be accomplished by throttling the LEM propulsion engine to attain desired terminal characteristics.

9.2 Command Module. - The CM will observe and photograph the entire letdown and landing phase and serve as immediate advisor (when requested), on trajectory status and abort procedures.

10. 87-107 Hours: LEM lunar touchdown to LEM countdown. - This period will extend from LEM touchdown through lunar exploration to initiation of the LEM prelaunch countdown.

10.1 LEM. - The primary duty of the LEM crew during this phase will be the completion of the lunar exploration and experiments utilizing the LEM as a base of operations. They will set up the television systems remote from the LEM to observe their activities and finally the LEM launch.

10.1.1 Lunar experiments. - The lunar experiments will be performed according to the program outlined in Appendix B for intervals of up to six hours. Concluding tests will be performed in the LEM. The LEM communications links will be used to transmit all possible information to the earth and CM as expeditiously as seen feasible by the crew.

10.2 Command Module. - The CM shall make photographs of the survey area on each pass and offer backup help when requested.

11. 107-111 Hours: LEM countdown to LEM lunar launch. - The crew will have responsibilities during this time similar to those of earth prelaunch. The LEM will be maintained in a near ready status at all times with top priority over the scientific objectives.

11.1 Vehicle inspection. - The vehicle will be inspected for damage incurred while on the lunar surface with special attention being given to the propulsion equipment.

11.2 Countdown. - The formal countdown procedure will be conducted with both the LEM and CM crews devoting top priority time to problem areas.

12. 111-112 Hours: LEM lunar launch to LEM/CM/SM rendezvous. The LEM propulsion system will be utilized for launch and insertion into orbital rendezvous position. The flight plan will begin with lunar liftoff of the LEM, continue through the elliptical parking orbit, and terminate with achievement of rendezvous position. The LEM propulsion system shall be capable of producing a ΔV up to 6117 feet per second to accomplish this phase.

12.1 Launch. - The LEM lunar launch and insertion into elliptical orbit will be accomplished by the LEM propulsion engine. Ignition will be possible either automatically or manually.

12.2 Transfer of orbits. - Transfer of the LEM from its elliptical orbit to the CM/SM circular orbit will be accomplished by orienting and activating the LEM propulsion system at the predetermined time.

12.3 Powered flight. - The crew shall monitor performance of all systems during powered flight and will have capability to override all automatic systems. Rendezvous procedures will be initiated immediately after injection into CM/SM orbit.

13. 112-117 Hours: LEM/CM/SM rendezvous to transearth injection. - This period will extend from initiation of rendezvous to transearth injection.

13.1 Rendezvous and docking. - The rendezvous and docking maneuvers will be accomplished by the LEM with the CM taking corrective action as backup to the LEM guidance and propulsion systems. A ΔV capability of 600 feet per second will be required for completion of rendezvous and docking. The larger initial closure maneuvers will be performed with the LEM propulsion system and the finer final maneuvers will be completed with the LEM reaction control system. Both the LEM and SM attitude control systems will have a rate damping mode initiated at the onset of terminal docking maneuvers. One craft only will normally perform the maneuvers.

13.2 Primary transfer. - The transfer of crew and lunar samples and data from the LEM to the CM will begin immediately after the LEM is mated and secured to the CM. The LEM will be separated upon completion of the transfer operation.

13.2.1 Alternate transfer. - The crew, in event mating and docking is considered inadvisable, will leave the LEM and proceed to the CM using soft teathered techniques. Samples and data from the lunar experiments and exploration may be transferred also if they do not hamper crew survival.

14. 116-188 Hours: Transearth injection to reentry. - The transearth flight period will encompass all operations required to reach the earth reentry point from lunar orbit.

14.1 Launch for lunar orbit. - The launch phase will be initiated by ignition of the SM propulsion system. Ignition will be accomplished either automatically or manually at a preplanned time.

14.1.1 Powered flight. - Powered flight will extend from SM propulsion engine ignition to shutdown. A total ΔV of 0 to 3110 feet per second is anticipated to achieve lunar escape and injection on a transearth trajectory.

14.2 Coast phase. - The coast phase will begin with SM engine shutdown. The coast phase activities cover three major areas.

14.2.1 Trajectory checks. - Trajectory checks will be made at 1.6 hour intervals, beginning with transearth flight injection to determine flight path position and error accumulation.

14.2.2 Midcourse correction. - Midcourse corrections will be performed during the transearth flight. A total ΔV of 500 feet per second is anticipated. Midcourse maneuvers will be accomplished by orienting the spacecraft to the required thrust vector using the SM reaction control system and attaining the required ΔV using the SM propulsion system. Any plane change necessary during the transearth flight should be accomplished at the earth's sphere of influence, however, this is anticipated in trajectory design.

14.2.3 Staging. - The SM will be jettisoned after confirmation is made that trajectory is satisfactory midcourse corrections are unnecessary. Techniques will be such that 2 hours are allowed between planned jettisoning of the SM and encountering the outer Van Allen belt for emergency action in case of "hand-up".

15. 188-189 Hours: Reentry to earth impact. - This interval shall begin with entry into the earth atmosphere and include all events occurring until earth impact.

15.1 Reentry. - The reentry period begins with initial interaction of the CM with the earth's atmosphere and continues until drogue chute deployment. The crew will have the responsibility of monitoring systems and guiding the spacecraft to a preselected landing area by using roll modulating the life vector.

15.2 Landing. - The landing phase begins with drogue chute deployment, include afterbody jettison and main chute deployment, and terminates at earth touchdown. The crew will monitor the landing sequence, initiated events manually where required, make impact point calculations and relaying information to recovery forces to expedite recovery.

16. 189-261 Hours: Earth landing to recovery. - This interval will include all operations and events performed from the time of landing until pickup of crew and vehicle by recovery forces.

16.1 Landing. - At landing the crew will confirm landing, jettison landing equipment, and secure CM for 72 hours recovery forces.

16.1.1 Flotation. - The CM will be secured to assure stability and flotation for water landings.

16.1.2 Recovery aids. - All recovery aids will be deployed and operating within one hour after landing.

16.2 Recovery. - The operational phase of the mission will be concluded upon the safe recovery of the Apollo crew and vehicle.

APPENDIX B

SCIENTIFIC OPERATIONS

The selection of scientific payloads for the LEM mission is based on many factors, such as, the probable state of knowledge at the time of landing, weight allowance, and the length of stay on the lunar surface. Since the LEM will perform the initial landings it is logical to concentrate the scientific capabilities on gaining information of a selenological nature. The crew member in the command module in lunar orbit also contributes to scientific objectives of the LEM by photographic survey of the lunar surface and by making other general observations of the characteristics of lunar topology and surface features. The scientific objectives outlined in the following discussion can be accomplished in a 24 hour residence time on the lunar surface. The experiments described are considered typical for all initial missions. General descriptions of the experiments to be carried out are given, including a discussion of the type of instrumentation required. Weight and volume requirements are included in table 13, paragraph 9.8.1.

The success of the mission depends on the ability of the LEM crew to exercise selectivity and provide judgment.

Each instrument or equipment has its own power supply and other service requirements necessary to perform the experiment. Controls and general handling characteristics will be compatible with the crew in pressurized space suits or in the LEM pressurized cabin with an open face plate. The experiments have been divided into 3 phases to fully utilize the two-man crew during the residence time. They are: Phase I, the period following lunar touchdown checkout; Phase II, rest period; Phase III, the period following the rest period and before the final countdown. During this period, film and records will be processed as well but as second priority to operational requirements.

PHASE I

Radioactivity Survey

A radioactivity survey will be made to determine if readioactive deposits exist in the immediate landing site.

Instrument - - GM Counter.

Temperature Measurements

A survey will be made to measure surface temperature and at various depths below the surface.

Instrument - - Thermocouple with probe and recorder.

Surface and Rock Formation Detail

To obtain information on rock formation and general terrain, the landing area will be photographed in detail.

Instrument - - Camera capable of operation in the infrared, visible and ultra violet region of the spectrum.

Rock Survey

Rock and soil samples will be collected from the landing area to be analyzed with the aid of a microscope and photographed so only a selective few samples are required to be returned to earth.

Instrument - - Geological pick and net container.

Communications Experiment

A communication experiment will be carried out between the LEM and the crew to obtain signal strength from various points on the surface and the LEM.

Instrument - - Signal strength meter with directional antenna.

Rock and Soil Analysis

The rocks and soil samples will be photographed with the aid of a microscope to obtain maximum data so only a few selected samples be returned to earth.

Instrument - - Microscope and camera

PHASE II

Rest Period

Film development and record preparation.

PHASE III

Friction Coefficient of Lunar Surface

An experiment to determine coefficients of static and rolling friction of the lunar surface will be conducted.

Instrument - - Drag Bar.

Surface Soil Density

Instrument - - Insitu soil sample.

Core Sample

Core samples of the lunar sub-surface will be taken at a number of selected places at depths up to 5 feet to be returned to earth for analyses.

Instrument - - Explosive charge drill and core sampling device.

Seismograph Studies

A seismograph method utilizing acoustic sources to create shock waves will be used to examine the moon's interior.

Instrument - - Seismographs (2) and acoustic sources.

Residual Atmosphere Studies

A study will be made to determine if the moon contains a gaseous atmosphere.

a. Chemical composition

Instrument - - Mass spectrometer

b. Density

Instrument - - Mass spectrometer

c. Pressure

Instrument - - Redhead gauge

Gravity

An experiment to determine the value of gravity at the landing area will be conducted.

Instrument - - Pendulum system or gravimeter.

[redacted]

Magnetic Field Strength

An experiment to investigate the existence of a magnetic field or fields will be conducted.

Instrument - - Magnetometer.

[redacted]

APPENDIX C

RADIATION ANALYSIS

The LEM radiation hazard is considered to exist from solar proton events only and since the manned portions of the LEM mission occurs in the close vicinity of the moon, the moon will intercept a large number of particles. For the purpose of this analysis it will be considered that the flux described under the natural environment Section 6.1.1 is reduced 25 percent.

The inherent shielding provided by the structure and equipment of the LEM was determined by breaking up the vehicle into six solid angles centered on the crew. The analysis considers the crew to be represented by cylinders of water as described in reference 4. The total dose considers the contribution of ionization by primary and secondary particles.

The secondary particles contribution to the dose was obtained by the method described in reference 5. This method assumes that the upper limit for secondary production can be set by assuming a cross-section of one barn. The dose delivered by these secondaries is determined by their energy deposit in tissue. Their energies have a wide spread and there are many fast particles as well as some star production. The dose delivered along the track is some multiple of the minimum ionization. In water the minimum ionization, (dE/dX) min, 2 MEV CM^{-2}/gram, so the dose per particle is 2 MEV CM^{-2}/gram. Utilizing the flux equation for secondary particles given in Section 6.1.2. The secondary dose rate per primary proton/CM^{-2} is given by

$$D_s = .6\sigma \times 10^{-24} \left[2\right]\left[N > E\right]$$

It is necessary to consider the various radiation types. Very high energy particles can produce fast minimum ionizing particles, but there will also be slow mesons, star production, and neutron production. Slow means are expected to ionize up to 20 times the minimum initially but at the end of their track the ionization is only a few times minimum. Stars produce a very heavily ionized path and is approximately 10. Neutrons do not contribute to the dose at all until they interact to produce knock on protons. These protons may have of λ of 10. Thus, if the mean free path for neutron scattering is about 10 grams/CM^2 the average ionization produced by the neutron per gram CM^2 of their path corresponds to a λ of 1. Accordingly a λ of 5 is taken as a reasonable upper limit for secondaries. In other words, the average rate of energy loss due to secondaries is 10 MEV/gram CM^{-2} in tissue.

The total dose for the various body organs are as follows:

Skin	495 RAD	Allowable 500
Blood forming organs	52 RAD	Allowable 220
Eyes*	100 RAD	Allowable 100

*With 12.6 lb. of Lucite Shield

APPENDIX D

METEOROID PENETRATION ANALYSIS

The analysis of the meteoroid penetration hazard was accomplished by the utilization of the meteoroid flux given in table 2 and the Summers penetration equation:

$$T = 3.42\, D_p \left(\frac{E_p}{E_t}\right)^{2/3} \left(\frac{V}{C}\right)^{2/3}$$

T = Penetration Depth
D_p = Diameter of impacting particle
E_p = Density of particle
E_t = Density of target
V = Velocity of particles
C = Velocity of sound in the target material

A bumper construction, that is, a double wall construction is considered to reduce penetration of 80 percent of that of an unprotected surface. A filled double wall construction is considered to reduce penetration to 84 percent of that of an unprotected surface.

The overall reliability of the vehicle is taken as .99 for the LEM mission.

[redacted]

APPENDIX E

SPACECRAFT INTERFACES

Spacecraft modules interfaces will be the same as those presently conceived for Apollo. Mechanical, electrical electronic, fluid, and gas interfaces may take on varied configurations. Their mechanical separation will achieve its greatest reliability through mechanical simplicity and careful considerations in the detail design. These interfaces must be the subject of a detailed study. The interfaces between the Command Module, Service Module-adapter and the Lunar Excursion Module are of particular concern here and are considered briefly.

The mechanical interface, as far as structural allignment and docking, is the only aspect considered in any detail at this point. Consideration of electrical, electronic, communication, and environmental interfaces will be subject to a later detailed design study.

LUNAR EXCURSION MODULE INTERFACES

General interface considerations lead to several points which should be amplified here.

ACCESS FOR SERVICING

The LEM in the earth launch configuration is serviced through access panels in the adapter and interstaged structure. These panels are properly located to permit servicing of equipment on the aft face of the Service Module and the Service Module propulsion system.

STRUCTURAL ATTACHMENT TO ADAPTER

The structural attachment to the adapter is at four points each of which are disconnected by explosive latches controlled from the Command Module through the electrical umbilical in the docked configuration. Computer and inertial platform is slaved between LEM and CM for storage or orbit parameters.

Upon injection into a translunar trajectory, the Command Service Modules are separated from the S IV B. The afterbody heat protection cap is then removed by a remotely controlled mechanical or electrical actuator and the CM/SM is freely flown into an airlock transfer attitude with the LEM. When the two modules are properly locked in position, the LEM is released from the adapter and pulled from the S IV B.

[redacted]

Prior to airlock use, inflatable seals are actuated between the interlocked modules, pressure equalization is accomplished, and preparations for crew transfer are initiated.

All docking interfaces will have the capability of retraction and reuse. Seals will be deflated, airlock will be de-pressurized and separation will be remotely controlled through mechanical or electrical means within the Command Module.

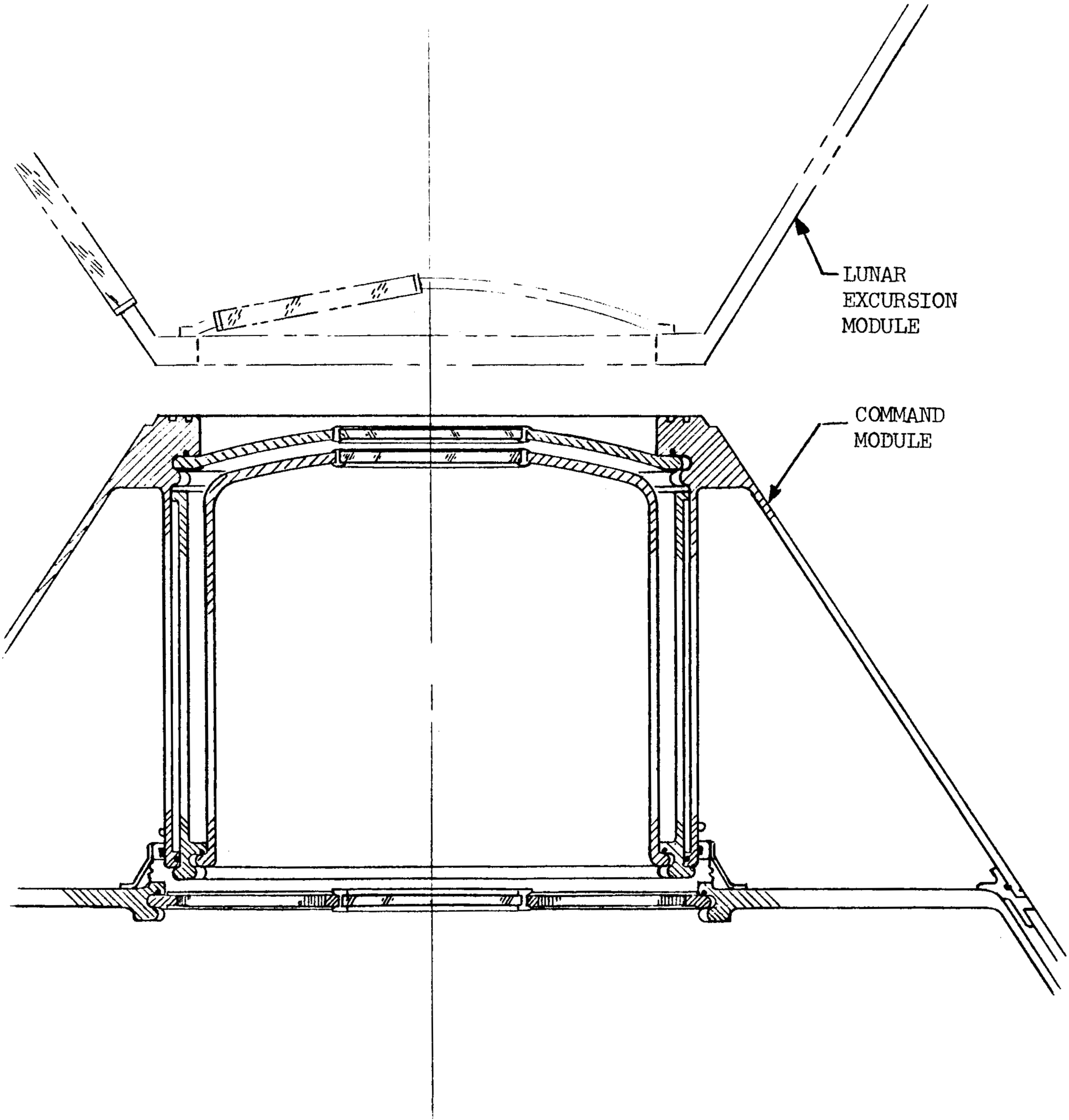


FIGURE E-1.- PROPOSED DOCKING FACE AND AIR LOCK

[redacted]

APPENDIX F

LUNAR LANDING CONSIDERATIONS

The lunar excursion module, having transferred from lunar orbit through the letdown trajectory into a hovering condition faces the problem of accomplishing a relatively soft and stable landing. The spacecraft, landing on the model lunar surface predicted in reference 2, is limited in its control of horizontal and vertical velocities. The landing gear must be designed to attenuate the energy, minimize rebound, provide stability and provide attitude control satisfactory for launch. Here, two conditions of impact are reviewed.

Condition I

The LEM is assumed to land on all four legs at approximately the same time.

$$(1) \qquad V_H = \sqrt{\frac{(k^2 + b^2)(2g_L \Delta h)}{b^2 \cos^2\theta}} + V_V \tan\theta$$

Condition II

Here the LEM touches down on two of the four legs. The landing loads impart a pitching moment to the LEM

$$(2) \qquad V_H = \frac{k^2 + b^2}{(b\cos\psi)(k^2+b^2\cos 2\psi)} \sqrt{\frac{(k^2+b^2)^2(2g\Delta h) - (k^2+b^2\cos 2\psi)^2(2gb)(\cos\psi - \cos(\psi+p))}{k^2 + b^2}} - V_V \tan\psi$$

It can be seen from equations 1 and 2 that the vertical velocity may aid in stability in one case while it will be detrimental in another.

In approaching the problem we consider that all translational energy in converted to shock strut absorption and to energy in rotation. This rotational energy must not exceed the energy necessary to raise the center of gravity to a tipover condition if stability is to exist.

Respectively: K.E. $\leq$ P.E. or $1/2\ I\omega^2 = \omega\Delta h$

From this point we may assume a spread of gear, determine the change in height of the C.G., and calculate the horizontal and vertical velocity limits.

The minimum required R/a to stabilize the LEM under impact conditions of 5 fps. horizontally and 10 fps vertically is approximately .8. Therefore, using a spread of 1.1 to 1 should give the desired performance and still leave a substantial safety factor.

[redacted]

LANDING GEAR SHOCK STROKE

In calculating the stroke of the landing gear we assume that a constant density crushable honeycomb material with a 75 percent compression efficiency is used.

The gear is designed to absorb the shock of a vehicle impacting at 10 feet per second while limiting the force delivery to the vehicle to 4 earth gravities.

Here, the kinetic energy of impacting will equal the work done in stopping the vehicle. $KE = W$

Then, $$\text{Stroke} = \frac{V^2}{2gh}$$

For a constant density structure the required stroke is 27.6 inches. Therefore the 30 inches provided in the proposed design is ample to attenuate the vertical loads. Provisions have been made for attenuation in the horizontal plane through angular set of the main shock strut and crushable side material in the landing pad.

Landing Pad Dimensions

On impact the honeycomb structure having been designed to yield at a force of 1 earth gravity, will transmit this same force to the lunar surface. This force divided by the surface soil bearing pressure will give us a required landing pad area.

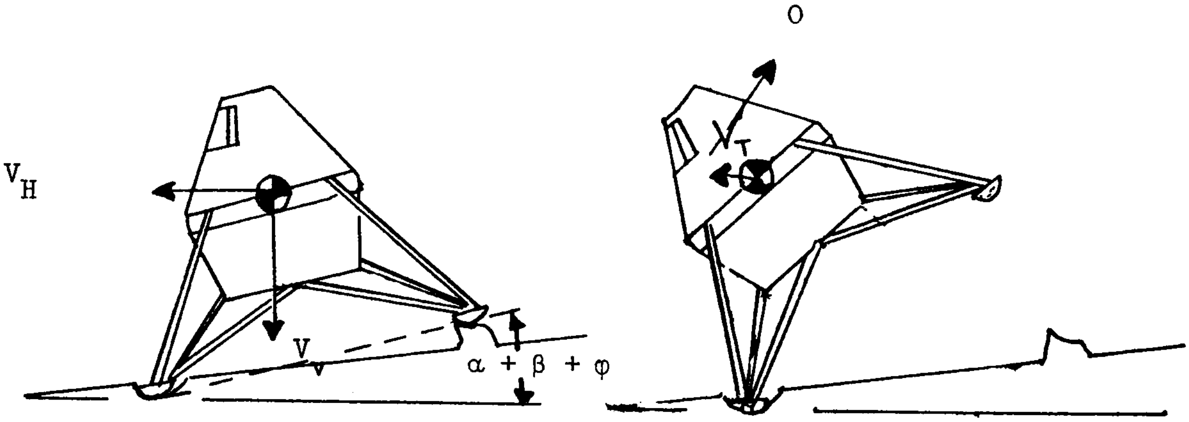
$$A = F/P_{BS}$$

$$D = 2\sqrt{\frac{W}{\pi P_{BS}}}$$

Considering a maximum lunar touchdown weight of 16,000 pounds, and a surface soil bearing pressure of 12 psi the required impacting area per pad is 1333.3 square inches or in case of circular pads, a diameter of 41.2 inches. This is comparable to the design 42 inches pad diameter.

It should be evident from the above calculations that the proposed spacecraft design is more than capable of handling the problems of tipping moments and impacting loads as set up in the design criteria.

CONDITION I



1.

2.

CONDITION II

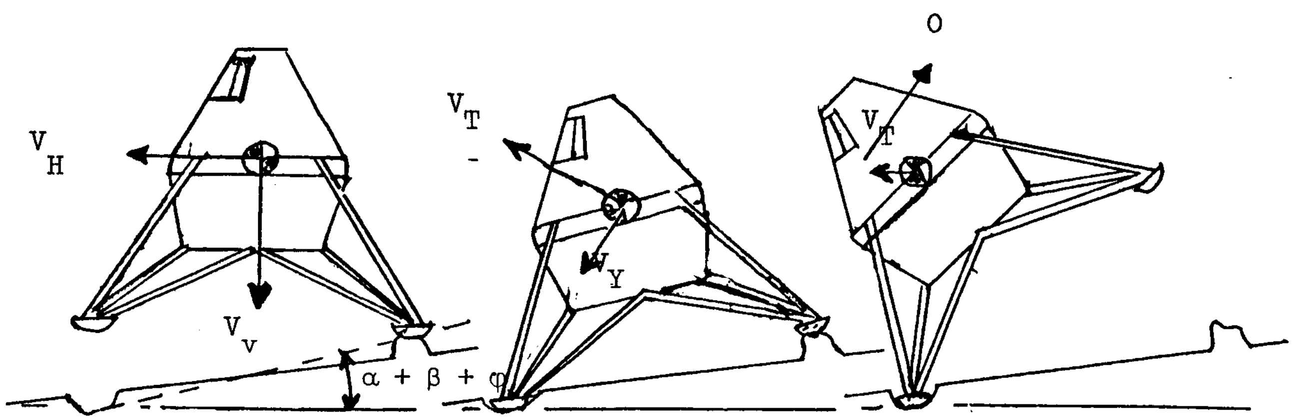


FIGURE F-1.- CONDITION I AND CONDITION II

[redacted]

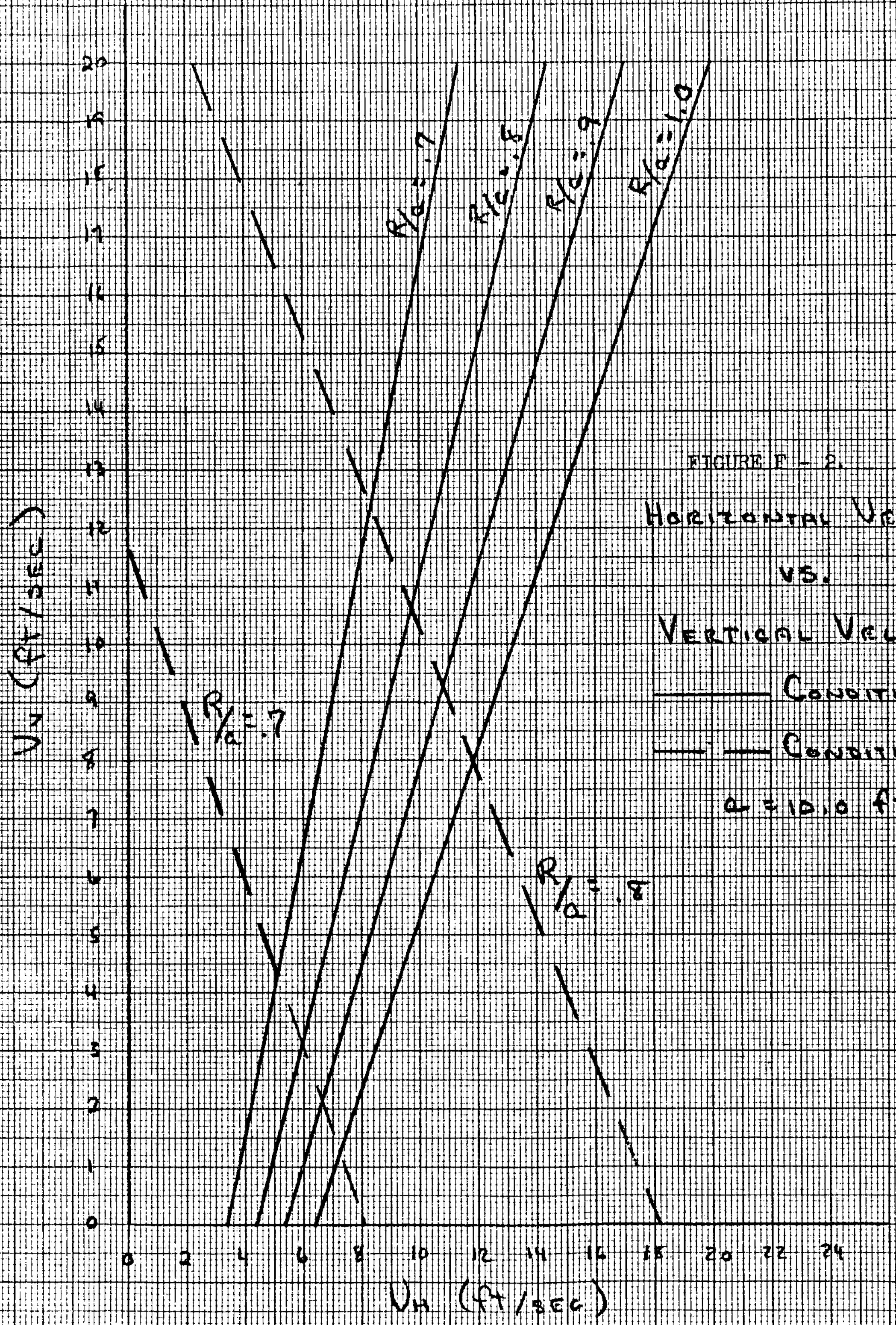


FIGURE F - 2.

HORIZONTAL VELOCITY
VS.
VERTICAL VELOCITY

——— CONDITION I

— — CONDITION II

a = 10.0 ft

[redacted]

APPENDIX G

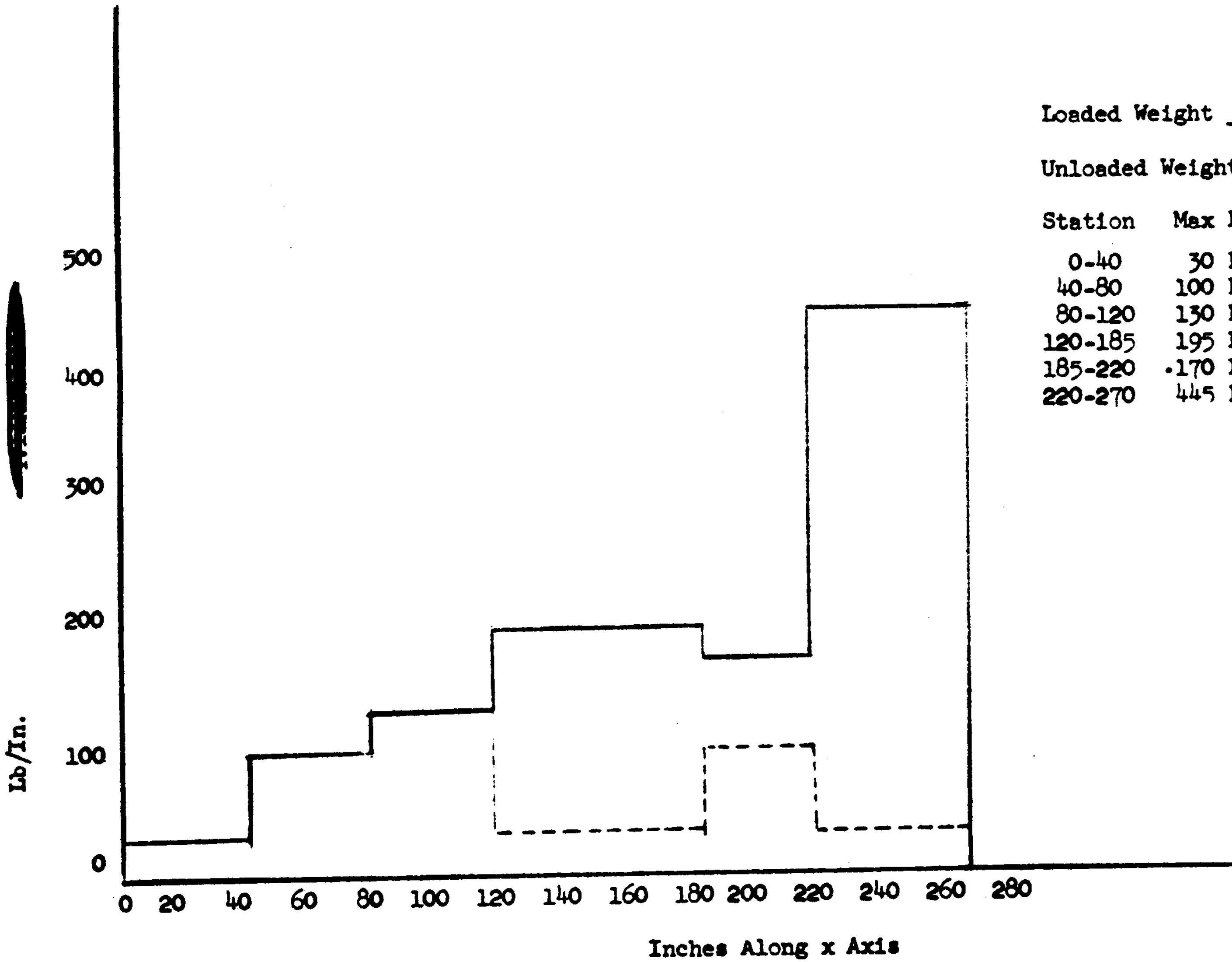
WEIGHT DISTRIBUTION

Weight distribution charts are included for use in structural dynamics preliminary analysis. Charts G1-G5 give weight in pound/inch against inches of span. Weight distributions can be plotted along any axis, however, at the present time the information is not available and preliminary charts are included along the X axis only. The degree of concentration or distribution of loads is not included.

[redacted]

COMMAND MODULE AND SERVICE MODULE WEIGHT DISTRIBUTION

FIGURE G-1



Loaded Weight _____

Unloaded Weight -----

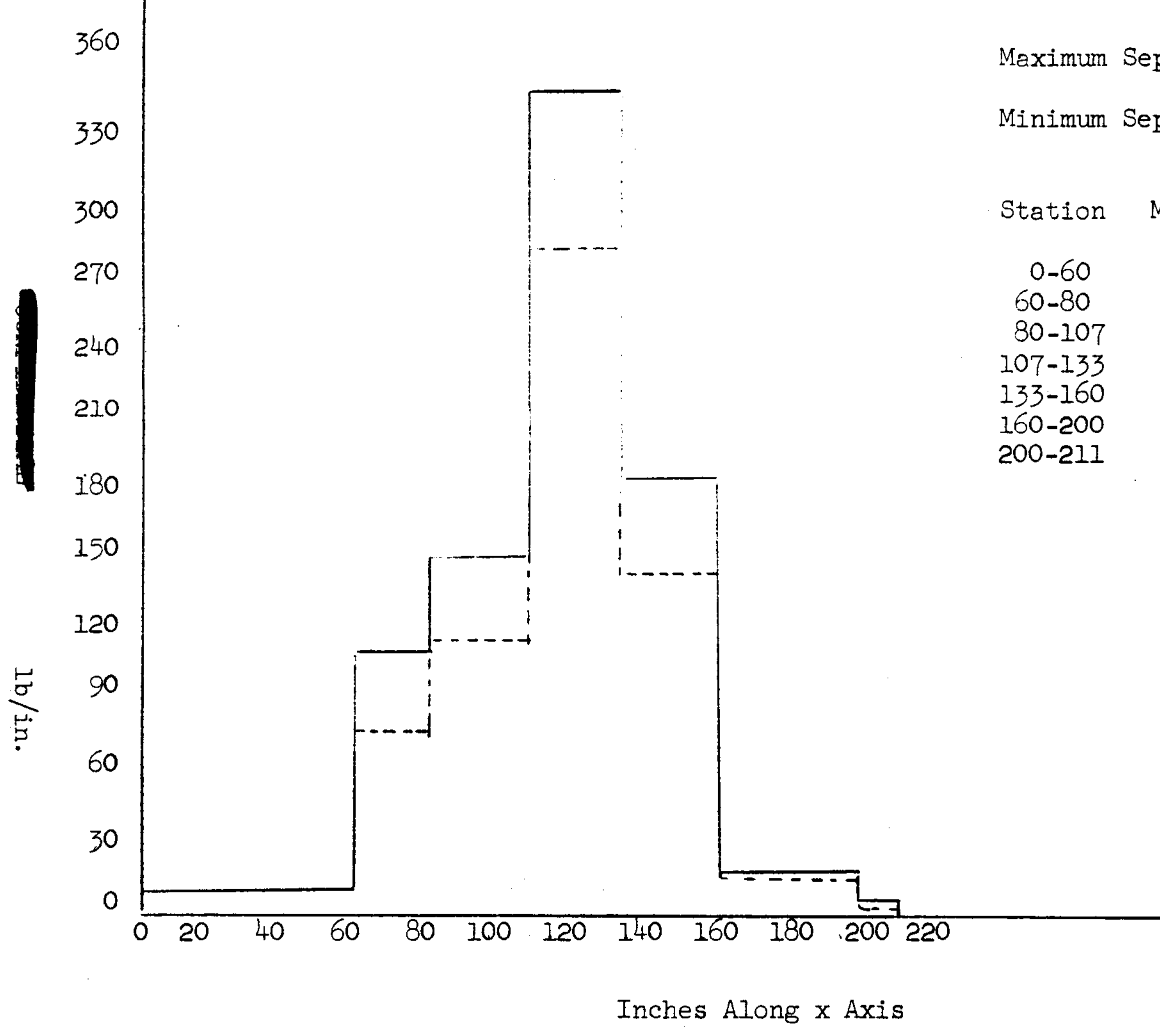
Station	Max Lb/In.	Min Lb/In.
0-40	30 Lb/In.	
40-80	100 Lb/In.	
80-120	130 Lb/In.	
120-185	195 Lb/In.	35 Lb/In.
185-220	·170 Lb/In.	100 Lb/In.
220-270	445 Lb/In.	35 Lb/In.

[redacted]

[redacted]

MAXIMUM AND MINIMUM SEPARATION WEIGHT DISTRIBUTION

FIGURE G-2



Maximum Separation Weight ______

Minimum Separation Weight -------

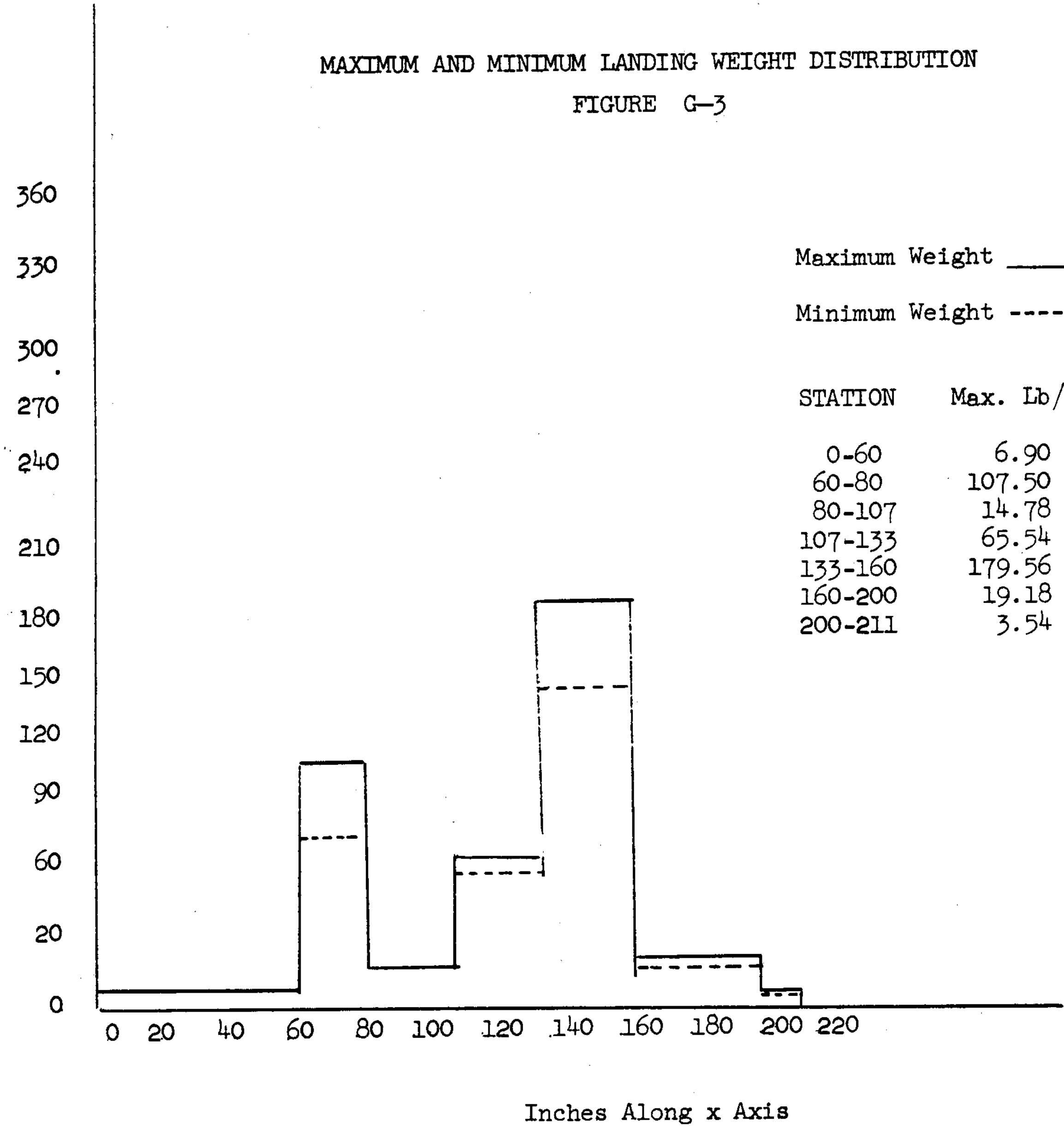
Station	Max Lb/In.	Min Lb/In.
0-60	6.90	6.90
60-80	108.60	74.75
80-107	147.96	114.74
107-133	324.81	276.35
133-160	179.56	142.11
160-200	19.18	15.35
200-211	3.54	2.82

[redacted]

[redacted]

MAXIMUM AND MINIMUM LANDING WEIGHT DISTRIBUTION

FIGURE G–3



Maximum Weight ________

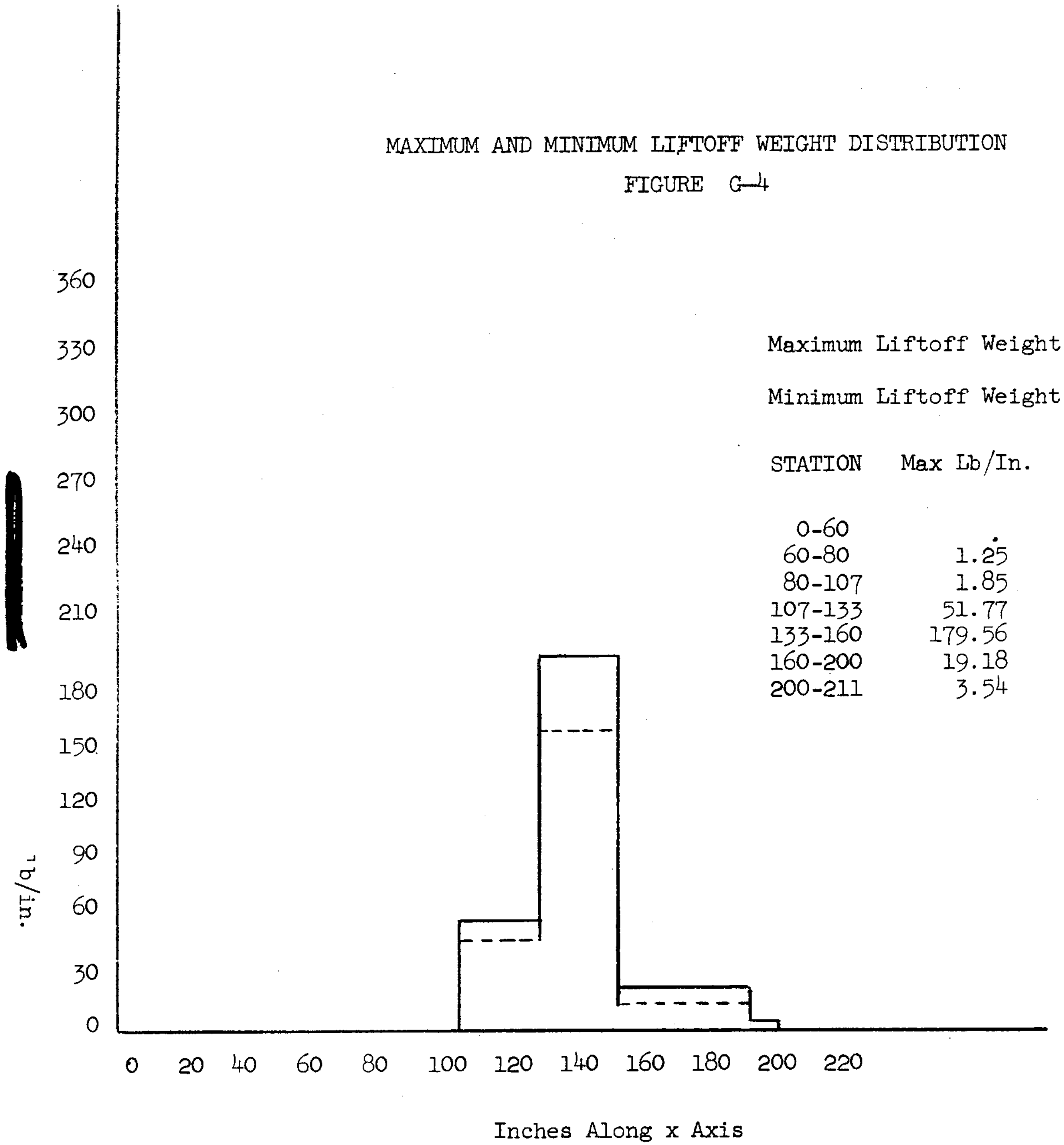
Minimum Weight -------

STATION	Max. Lb/In.	Min. Lb/In.
0-60	6.90	6.90
60-80	107.50	73.65
80-107	14.78	14.78
107-133	65.54	58.81
133-160	179.56	142.11
160-200	19.18	15.35
200-211	3.54	2.82

[redacted]

MAXIMUM AND MINIMUM LIFTOFF WEIGHT DISTRIBUTION

FIGURE G-4



Maximum Liftoff Weight ________

Minimum Liftoff Weight --------

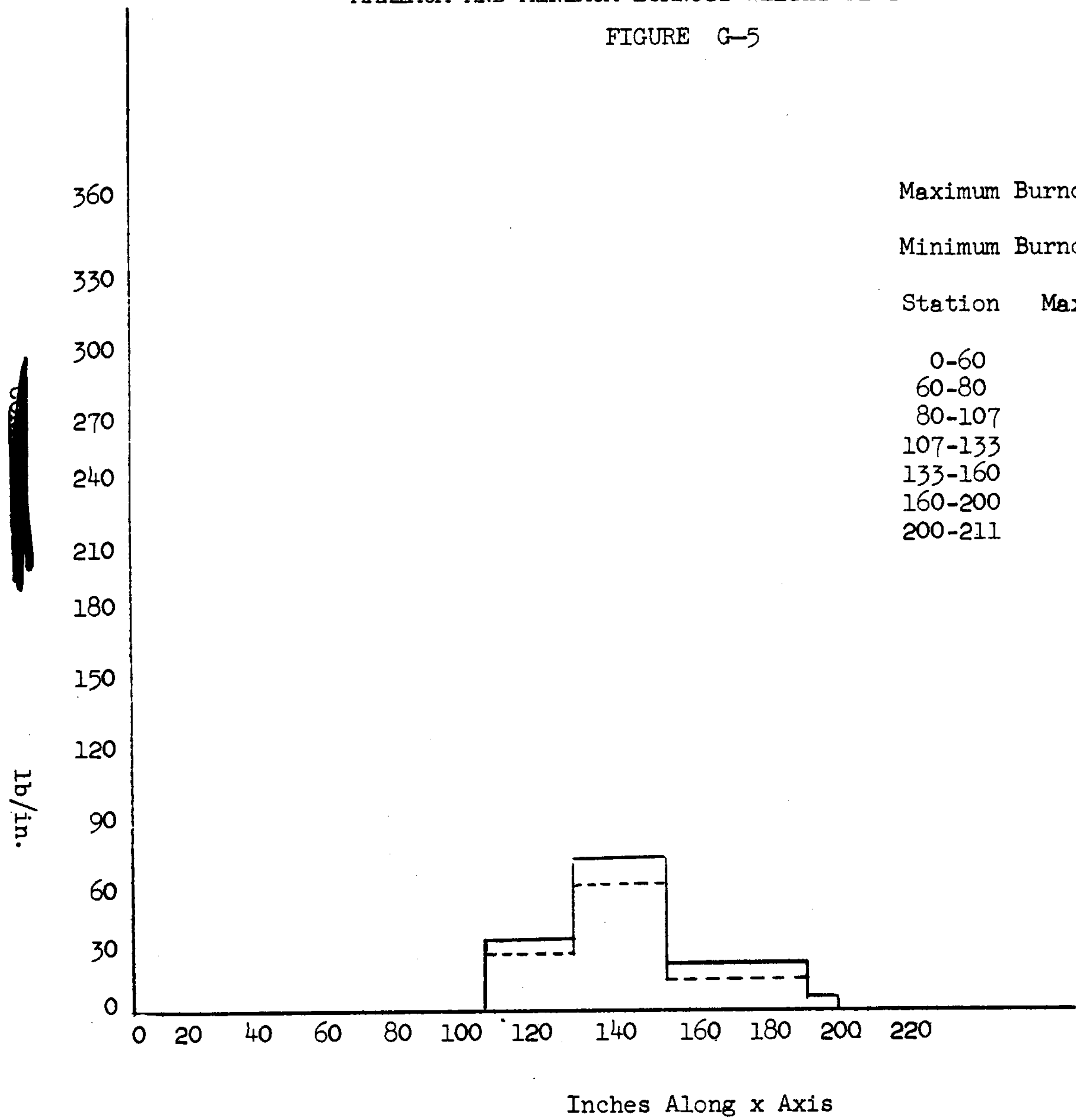
STATION	Max Lb/In.	Min Lb/In.
0-60		
60-80	1.25	1.25
80-107	1.85	1.85
107-133	51.77	45.10
133-160	179.56	145.00
160-200	19.18	15.35
200-211	3.54	2.82

[redacted]

[redacted]

MAXIMUM AND MINIMUM BURNOUT WEIGHT DISTRIBUTION

FIGURE G-5



Maximum Burnout Weight ______

Minimum Burnout Weight -----

Station	Max Lb/In.	Min Lb/In.
0-60		
60-80	1.25	1.25
80-107	1.85	1.85
107-133	29.31	27.20
133-160	66.93	55.70
160-200	19.18	15.35
200-211	3.54	2.82

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APPENDIX H

MODIFICATION OF THE LEM FOR EARTH TRAINING

1. Summary. - The modifications to the LEM and its systems described here represent a first approximation for the solution of the problem of earth based training to simulate the terminal maneuver for lunar landing. It is clear from the work presented here in conjunction with that presented in the main text that this approach leads to an economic solution to the problem, achieving a realistic simulation of lunar landing.

2. Introduction. - The purpose of this study is to present a broad picture of the modifications to the LEM necessary to operate it as a training vehicle for use on the earth. This approach is of particular interest due to advantages in economy, realistic crew training, and flight hardware qualification.

3. Guidelines. - The guidelines are based on operation of a modified LEM as an earth training vehicle and are a collection of principles to which the basic technical approach must be responsive.

3.1 Mission scope. - The modified LEM is designed for either manned or unmanned flight in the earth environment, with flight capability to simulate the terminal maneuver for landing on the moon.

3.2 Escape. - There shall be a capability for escape from the vehicle at any time.

3.3 Spacecraft modifications. - Modifications shall be only those required to operate the LEM for earth training or for safety considerations.

4. Design criteria. - The design criteria for the modified LEM is the same as that of the LEM for the lunar landing mission except the following, which are a result of operating the vehicle in the earth environment.

4.1 Structure. - Structural design criteria is the same as for the LEM except the following.

4.1.1 Design cases. - Those design cases based on considerations of the launch vehicle or the space environment are eliminated.

4.2 Guidance and control. - The guidance and control design criteria are the same as that of the LEM except for the following.

4.2.1 Environment. - All guidance and control equipment shall be capable of operation in the earth environment.

4.2.2 Hover and translation. - The hover and translation maneuver shall be considered performed at 300 feet altitude.

4.2.3 Unmanned flight. - In conjunction with the communications system the guidance and control systems shall provide for unmanned flight of the modified LEM using ground originated commands.

4.3 Propulsion system. - The propulsion system design criteria shall be the same as that for the LEM except the following.

4.3.1 Propellant loading. - The propellant loading shall be developed to conform to the performance criteria with the specific impulse based on system operation in the earth environment.

4.3.2 Environment. - The propulsion system components shall be altered or adjusted for operation of the system in the earth's atmosphere at 14.7 psia.

4.4 Communications system. - The design criteria for the communications system is the same as those for the LEM except as follows.

4.4.1 Voice communications. - Voice communications shall be provided between the crew member and a remote control and monitoring station (line-of-sight).

4.4.2 Telemetry. - Ten-channel telemetry to a remote station (line-of-sight) shall be provided.

4.4.3 Remote control system. - Receivers and actuators necessary to operate the vehicle unmanned by remote control will be provided. The flight controller shall have visual contact with the vehicle.

4.4.4 Other systems. - All other communications systems except the radar altimeters and antennas may be removed from the vehicle.

4.5 Environmental control system. - Design criteria for the environmental control system are as follows.

4.5.1 Capability. - The system shall be capable of meeting crew requirements given in section 7 for a period of 1 hour in a natural environment as given in section 6.

4.6 Electrical power and distribution. - Design criteria for the electrical power and distribution systems shall be the same as those for the LEM except the following.

4.6.1 Location. - The system is located in the launch stage.

4.6.2 Power requirements. - The power requirements will be based on operation of all systems for a period of 1 hour.

4.7 Landing system. - Design criteria for the landing system are the same as that of the LEM except the following.

4.7.1 Landing surface environment. - Landing surface conditions are to duplicate as nearly as possible those predicted in reference 2.

4.7.2 Landing weight. - The maximum landing weight is to be the total weight of the modified LEM. This value is to be at least 5,860 pounds.

4.7.3 Landing velocities. - Initial landing system configurations shall be designed to allow a safe landing within limits 1.5 times those specified for the LEM. After demonstration of feasibility of achieving those velocities specified for the LEM a landing system designed to duplicate lunar stability of the LEM will be installed.

4.8 Reaction control system. - Design criteria for the reaction control system is the same as that for the LEM except the following.

4.8.1 Terminal docking condition. - The requirements for terminal docking are eliminated.

4.8.2 Ullage. - The requirements for ullage are eliminated.

4.9 Escape system. - The escape system shall provide the capability of ejection and recovery of the crew member within the following limits.

4.9.1 Velocity. - Horizontal velocity limits are 0 to 75 feet per second in any direction. Vertical limits are 0 to 75 feet per second either ascending or descending.

4.9.2 Altitude. - The escape system shall provide for the safe escape of the pilot at any altitude from 0 to 1,000 feet.

4.9.3 Attitude. - Attitude limits in pitch and yaw are 0 to 45 degrees.

4.9.4 Acceleration. - Accelerations applied to the crew member shall not exceed those specified in the performance criteria in reference 1.

4.9.5 Escape initiation. - A system to automatically initiate the escape procedure will be provided. It shall include sensors and logic system as required. Manual initiation will also be provided as a backup.

5.0 Performance criteria. - Performance criteria for the modified LEM are the same as that given for the LEM except the following.

5.1 Design velocity. - Design velocities shall be characteristic velocities developed in accordance with the flight plan given in Section 12.

5.2 Velocity reserve. - Velocity reserve shall be considered that capable of sustaining the vehicle in powered flight for 15 seconds.

5.3 Thrust to weight ratio. - The minimum thrust to weight ratio will be 1.1.

5.4 Space environment. - Those criteria in Reference 1 based on the space environment are eliminated.

6.0 Natural environment. - Design and operational procedures shall be in accordance with the natural environmental data presented here.

6.1 Pressure, density, and temperature. - Atmospheric pressure, density and temperature shall be considered as that of models established for either the Manned Spacecraft Center or the Flight Research Center.

6.2 Wind velocity. - Wind velocity shall be considered not in excess of 10 knots as any higher velocity would prevent lunar landing simulation.

7.0 Crew requirements. - Design and operational procedures for the modified LEM shall be in accordance with applicable data presented in Reference 1 based on the following considerations.

7.1 Mission endurance. - The mission shall consist of pre-flight checks, powered flight, and post flight checks not to exceed 1 hour.

7.2 Pressure suit. - The crew member is clothed in a pressure suit, either pressurized or unpressurized for the entire mission.

7.3 Crew. - The modified LEM crew is to consist of 1 man.

8.0 Configuration. - The modified LEM configuration is similar to that of the LEM except for the cabin alterations to install the escape system, landing gear installations to accommodate the earth environment and systems modifications as described in the following section.. The lunar excursion module modified for earth training is shown in Figure 1.

9.0 Systems description. - The systems will be the same as those used in the LEM except as follows.

9.1 Structure system. - The structure is the same as used for the LEM except for removal of the top hatch, part of the cabin, and the ejection seat installation.

9.1.1 Weight estimate. - The structure weight estimate is as follows:

Cabin structure	396
Minus top hatch	-12
Minus 25 percent of windows	-23
Minus 15 percent conical shell wt.	-22
Plus ejection structure	22
TOTAL	361 pounds

9.2 Propulsion system. - The propulsion system is identical to that used for the LEM except as outlined below.

9.2.1 Helium bottles. - The six helium bottles in landing stage are removed.

9.2.2 Thrust chamber. - The thrust chamber will be optimized for atmospheric operation.

9.2.3 Thrust chamber pressure. - The thrust chamber pressure is 165 psia. (Max. thrust = 6,450 lbs.)

9.2.4 Propellants. - Propellants are carried in the launch stage only.

9.2.5 Valves and regulators. - All valves and regulators are adjusted in accordance with the 165 psia chamber pressure.

9.2.6 Weight estimate. - Weight estimate for propulsion system is as follows:

Landing stage		767
N_2O_4 tank	235	
MMH tank	179	
Structure	314	
Plumbing, etc	39	
Launch stage		791

N_2O_4 tank	73
MMH tank	58
Structure	161
Plumbing	58
Engine	178
Helium tanks	200
Helium	16
Residual propellants	50
TOTAL INERT	1,558 pounds
Usable propellant	2,075
TOTAL PROPULSION SYSTEM	3,633 pounds

9.3 Crew and equipment. - There shall be one crew member equipped with a pressure suit.

9.3.1 Weight estimate. - The weight estimate for the crew and equipment is as follows:

Crew member	192
Pressure suit	25
TOTAL	217 pounds

9.4 Communication system. - All LEM communication system except the radar altimeter may be removed. The following equipment should be provided for earth training operation.

9.4.1 Line of sight communications. - A voice transceiver is provided for line of sight communication.

9.4.2 Telemetry. - A 10 channel telemeter is provided for vehicle monitoring and control.

9.4.3 Command receiver. - A command receiver and actuators are provided to allow remote control of an unmanned operation.

9.4.4 Weight estimate. - The weight estimate for this system is as follows:

Radar altimeter	50
Voice transceiver	1
10 channel telemeter	25
Command receiver	4
Antennas	20
TOTAL	100 pounds

9.5 Guidance and control system. - The guidance and control system is identical to the LEM.

9.5.1 Weight estimate. - The weight of this system is 287 pounds.

9.6 Environmental control system. - The environmental control system consists of a portable cooling system capable of operating in an atmosphere of poisonous gases.

9.6.1 Weight estimate. - The weight of this system is estimated to be 60 pounds.

9.7 Electrical power and distribution. - The electrical power and distribution system is identical to that of the LEM except for the number of batteries required.

9.7.1 Weight estimate. - The system weight estimate is as follows:

Power distribution	20
Batteries	25
TOTAL	45

9.8 Landing system. - The landing system shall consist of four space frames designed to meet velocity limits given in paragraph 4.7.3.

9.8.1 Weight estimate. - For initial weight considerations, the landing system is considered to be the same as the LEM.

Main struts	132
V struts	202
Landing pads	80
TOTAL	414

9.9 Temperature control system. - The thermal control system is passive insulation the same as that used for the LEM except for an addition of insulation to protect the landing stage structure as a result of the shortened propulsion engine.

9.9.1 Weight estimate. - The weight of this system is included in the structure weight.

9.10 Reaction control system. - The reaction control system is identical to that of the LEM except for the propellant loading required.

9.10.1 Weight estimate. - The weight estimate is as follows:

Inert system	50
Propellant	20
TOTAL	70 pounds

9.11 Display system. - The display system (control panel) is the same as that used for the LEM.

9.11.1 Weight estimate. - The system weight is 80 pounds.

9.12 Escape system. - The escape system is an ejection seat designed to meet the requirements noted in Paragraph 4.9.

9.12.1 Weight estimate. - The system weight is 250 pounds.

10.0 Weight statement. - The summary weight statement of the modified LEM is as follows:

Cabin structure	361
Crew + equipment	217
Communications system	100
Guidance + control system	287
Environmental control system	60
Electrical power and distribution	45
Reaction control system	70
Display system	80
Escape system	250
Non propulsive payload	1,470
25 percent growth	363
Maximum non propulsive payload	1,833
Propulsion inert	1,558
Landing gear	414
Propellant	2,075

Propulsion weight	4,047
TOTAL WEIGHT	5,860

11.0 Scaling considerations. - The following factors are given to indicate the scaling problems when trying to simulate lunar hover, let down and landing in an earth environment with a free flying, full scale spacecraft.

LUNAR	FACTOR		EARTH
Length L_L	$= 1$	$\times$	L_E
Gravity G_L	$= 1/6$	$\times$	G_E
Acceleration $\frac{L_L}{t_l^2}$	$= 1/6$	$\times$	$\frac{L_E}{T_E^2}$
Time^2 t_L^2	$= 6$	$\times$	T^2_E
Time t_L	$= \sqrt{6}$	$\times$	T_E
Mass M_L	$= 1$	$\times$	M_E
Length L_L	$= 1$	$\times$	L_E
Velocity $V_L = \frac{L_L}{T_L}$	$= \frac{1}{\sqrt{6}}$	$\times$	V_E
Force $= \frac{M_L L_L}{T_L^2}$	$= \frac{1}{6}$	$\times$	$\frac{M_E L_E}{T_E^2}$
Pressure $= \frac{M_L L_L}{T_L^2 L_L^2}$	$= \frac{1}{6}$	$\times$	$\frac{M_E L_E}{T_E^2 L_E^2}$

11.1 Discussion. - It can be seen from the scaling factors that free flying spacecraft in the earth gravitational field represent the lunar situation except for the atmospheric conditions and time measurement. A pilot flying the earth bound spacecraft would have to perform all tasks and respond in time periods which are shorter than those in the lunar environment by a factor of $1/\sqrt{6} = .41$. Dust particles could be simulated full scale and would exhibit proper trajectory, and visibility characteristics except for atmospheric perturbations. Velocity would be excessive by 6 and impingment problems would be more severe with energy excessive by a factor of 6.

11.2 Correlation

11.2.1 Handling. - It is considered that the earth bound spacecraft would be considerably "harder to handle" than the spacecraft operating in the lunar environment. This is due entirely to the time factors since it is clear that most action in piloting experience becomes more difficult as the time allowed grows shorter. The factor of .41 clearly is significant but it is considered that a pilot could be trained under those conditions. Where force components or functions of the throttling increments about that required for hover the accelerations on the earth could be one/one with those on the moon. If angles of bank and pitch are decreased by a factor of six on the earth, the horizontal accelerations and velocities would be one/one with those on the moon. Analogue simulators would be used to further train the pilot for the more relaxing tasks of lunar landing.

11.2.2 Thrust. - Throttleable engines would be operated at approximately 6 times the thrust they would have in the lunar environment. Pulse modulated engines would have to have their thrust levels increased by a factor of 6. Thrust increments about the hover requirements should be one/one with those in the lunar environment.

11.2.3 Orientation. - Identical angular attitudes would lead to horizontal accelerations in the earth environment which would be 6 times those experienced in the lunar environment. This would be tolerated but angles would be reduced to reduce the acceleration and velocities developed.

11.2.4 Materials. - Materials would normally be the same except that strengths would have to improve by a factor of 6 for the earth environment to handle the higher landing loads unless shock strut strokes are increased by a factor of 6 or the square of the resulting impact velocities are reduced to the lunar case. The later would probably be the proper approach.

11.2.5 Stability. - Stability characteristics would be properly simulated unless the material strengths for landing loads are not simulated properly. A minimum compromise would exist for the increased stroke but several techniques should be considered like landing at lunar velocities and reducing gear tread such that the stability height is reduced by a factor of 6.

11.2.6 Atmosphere. - Model tests in the atmosphere and in evacuated chambers would have to be conducted such that the atmospheric perturbation problems are brought to light and "fixes" are devised to achieve satisfactory simulation. These tests would involve scale models of thrusters or engines and scale particles. The models would normally be 1/6 linear scale with accelerations one/one and densities one/one.

12.0 Flight plan. - Design and operational data shall be in accordance with the flight plan data presented below.

12.1 Minimum time of flight shall be 100 seconds.

12.2 Typical trajectory. - A typical flight trajectory is as follows:

12.2.1 Accent. - Vertical climb to 300 feet altitude in 15 seconds. (Characteristic velocity = 488 feet per second.)

12.2.2 Hover. - Hover at altitude for 30 seconds with a horizontal translation from 0 to 750 feet with a maximum horizontal velocity of 35 feet per second.
(Characteristic velocity = 1225 feet per second.)

12.2.3 Descent. - Descent to 15 feet altitude at 10 feet per second in 28.5 seconds.
(Characteristic velocity = 885 feet per second.)

12.2.4 Touchdown. - Kill vertical velocity by applying a thrust equal to 1.1 times weight to decelerate vehicle at 3.2 feet per second and touchdown with a vertical velocity of 0 feet per second in 3 seconds. (Characteristic velocity = 97 feet per second.)

12.2.5 Reserve. - Reserve flight time equals 15 seconds. (Characteristic velocity = 483 feet per second.)

12.2.6 Characteristic velocity. - Total characteristic velocity for the mission is 3178 feet per second.

13.0 Conclusions. - Modification of the LEM for earth training will present a vehicle capable of realistic crew training. As stated in Section 11, vehicle control will be more difficult in the earth environment than in the lunar environment. Although limited performance is available it is sufficient for the training mission as it allows sufficient time for the crew member to "get the feel" of the operation. It will require the crew member to develop his capability to make valid decisions in the minimum time. Advantages and disadvantages of particular interest to this technique are presented below.

13.1 Advantages. - Modification of the LEM for earth training presents the following advantages.

13.1.1 Realistic training. - Crew members will train using a vehicle similar to that used for lunar landing. Most systems employed are identical to those used for the terminal maneuver.

13.1.2 Hardware qualification. - Hardware may be qualified as an integrated unit under flight conditions similar to those encountered in the lunar environment.

13.1.3 Ground support personnel training. - Ground support personnel will receive training and flight systems experience.

13.1.4 Research and development cost. - Research and development cost will be low as a result of concurrent development with the LEM.

13.2 Disadvantages. - Modification of the LEM for earth training offers the following disadvantages.

13.2.1 Vehicle responses. - Vehicle responses will vary from those to be expected in the lunar environment.

13.2.2 Translational accelerations. - Translational accelerations in the earth environment for any given pitch or yaw angle will be 6 times those encountered for the same angle in the lunar environment.

13.2.3 Crew size limitations. - Weight considerations will limit the training crew to one member.

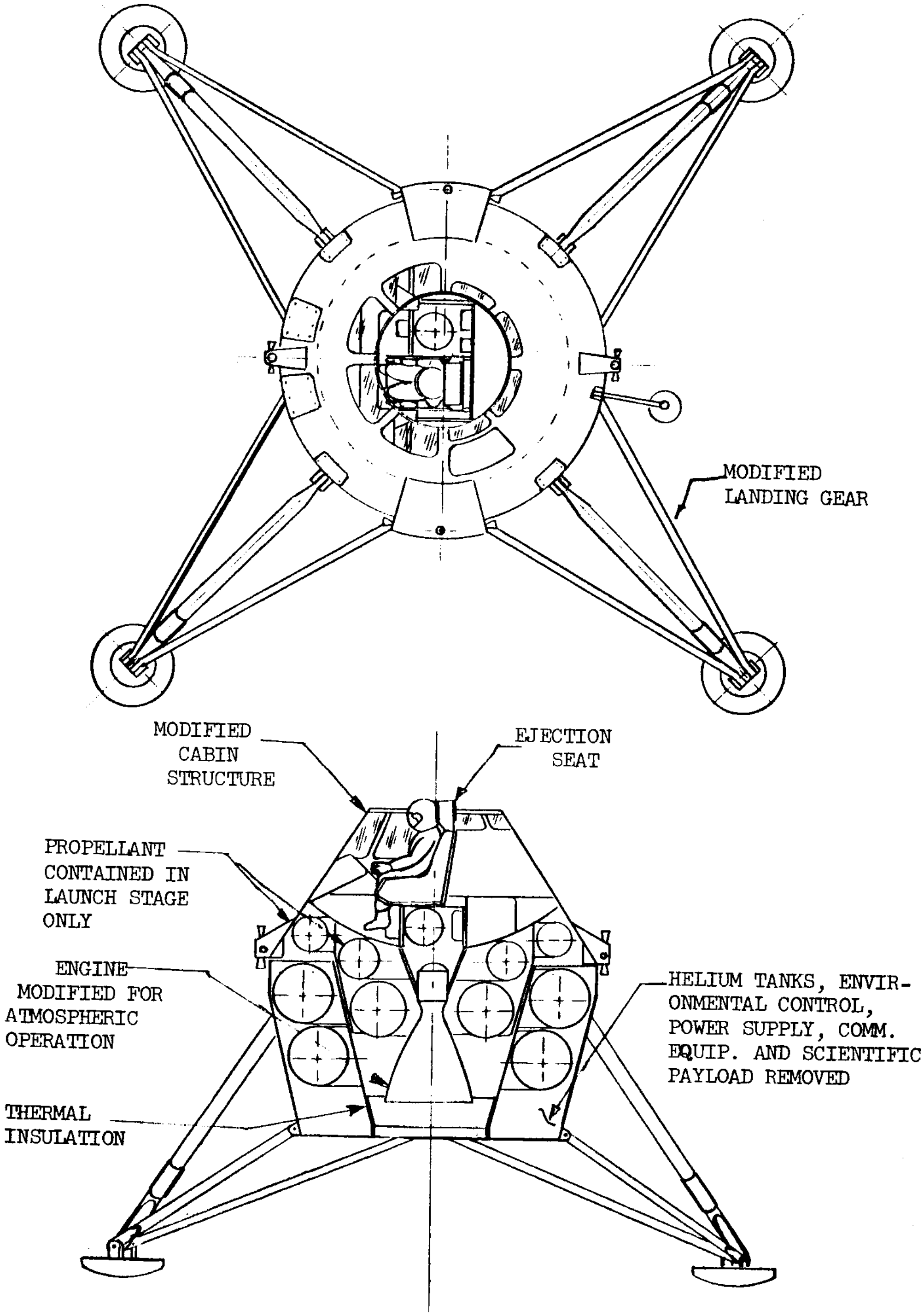

FIGURE H-1.- LUNAR EXCURSION MODULE MODIFIED FOR EARTH TRAINING

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